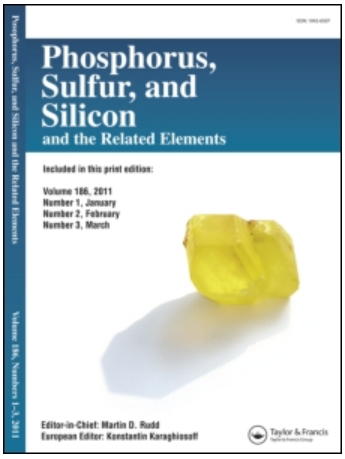

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Reactivity of the Acids of Trivalent Phosphorus and their Derivatives. Part X. Unexpected Reactivity of the >P-O$^-$ Anions Toward 2-Phenyl-3-Phenyl-Iminoindolenine N-Oxide

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REACTIVITY OF THE ACIDS OF TRIVALENT PHOSPHORUS AND THEIR DERIVATIVES. PART X*. UNEXPECTED REACTIVITY OF THE >P-O⁻ ANIONS TOWARD 2-PHENYL-3-PHENYL-IMINOINDOLENINE N-OXIDE

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(Received 2 December, 1997)

The reaction of the >P-O⁻ reagent with 2-phenyl-3-phenyliminoindolenine N-oxide **1** gave a reduction product, namely 2-phenyl-3-phenylimino-3*H*-indole **2** . Dialkyl phosphites undergo nucleophilic addition into the *endo* C=N double bond of the 2-phenyl-3-phenylimino-3*H*-indole **2** to furnish dialkyl 2-phenyl-3-phenylimino-2-indolinephosphonate **3**. The structure of the aminophosphonate **3** was established by X-ray crystallography.

Keywords: Nitrone deoxygenation; dialkyl 2-phenyl-3-phenylimino-2-indolinephosphonate; dialkyl phosphite

INTRODUCTION

Aminoxyls continue to play a central part among various organic stable free radicals. They have found application as spin labels, in spin trapping experiments[2] and also for the elaboration of organic magnetic materials which is a current target in materials science[3]. With the rapid growth of interest in EPR imaging and related techniques[4], a number of aminoxyls have been prepared in the search for useful contrast agents.

* Part IX see Lit [1].
† Corresponding Author.

Among different aminoxyls indoline aminoxyls have been extensively studied in different contexts. Greci found, that they gave a product substituted in the phenyl ring in the reaction with oxygen centered radicals; on the other hand they gave O-alkyl-hydroxylamine derivatives in the reaction with carbon centered radicals[5].

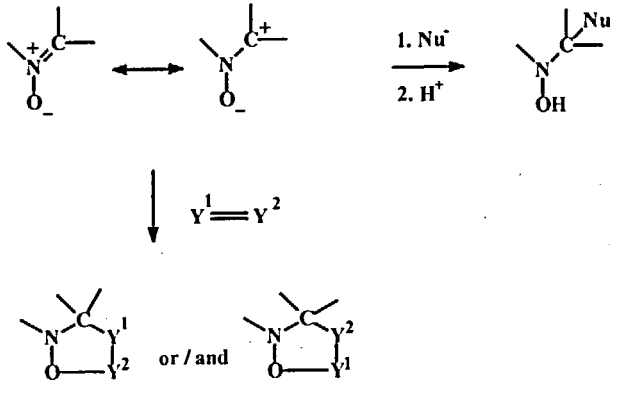
Paul Tordo has developed in recent years the chemistry and applications of the 2-phosphonylpyrrolidine aminoxyl radical[6] and found them to be superior in many instances to 5,5-dimethyl-1-pyrroline N-oxide (DMPO).

The properties of the α- phosphorylated aminoxyls prompted us for the synthesis of dialkyl 2-phenyl-3-phenylimino-2-indolinephosphonate as a precursor of α-phosphorylated indoline aminoxyl.

RESULTS AND DISCUSSION

One of the main routes for the synthesis of the α-phosphonylated indoline aminoxyl seems to be the addition reaction of a phosphorus reagent to a nitrone derivative of indoline. Furthermore, Colonna and Greci[7] have developed the chemistry of indoline nitrone and made this class of compounds easily available.

Nitrones are a particularly interesting class of compounds by virtue of their utility in organic synthesis. They are reactive starting materials in a large number of 1,3-dipolar cycloadditions[8] and can act as electrophiles with a variety of both carbon[9] and heteronucleophiles[10] (Scheme 1).



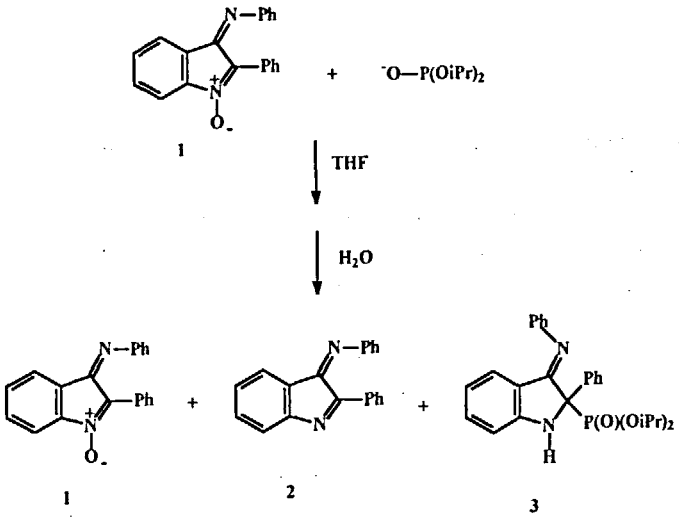
SCHEME I

Lusinchi[11] discovered that trialkylphosphites in alcohols as a solvent with nitrones gave dialkyl α-alkoxyaminophosphonates; in acetic acid they yield, on the other hand, iminophosphonates; however, trimethyl as well as triethylphosphite in the presence of triethylamine react with nitrone to yield imine. In contrast to that, Tronchet[12] and Vasella[13] have been able to demonstrate nucleophilic addition of the dialkyl phosphites to aldonitrones.

2-Phenyl-3-phenylimonoindolenine N-oxide **1** possesses in its structure two C=N double bonds; it was of our interest to check which double bond will add dialkylphosphites as well as H_3PO_3.

We have run the experiment with nitrone **1** and $H_3PO_3$with the expectation that phosphorous acid would protonate the oxygen atom and add into the C=N double bond of the nitrone structure to furnish α-hydroxyaminophosphonic acid. From the reaction mixture of nitrone **1** and H_3PO_3 in THF we have isolated only the starting material.

The treatment of nitrone **1** (1 equiv.) with sodium diisopropylphosphite (1 equiv.), on the other hand, gave a complex mixture of products. We have isolated: starting material **1**, imine **2** and diisopropyl aminophosphonate **3** (Scheme 2).



SCHEME 2

Fortunately, the phosphonate **3** crystallized in such a way that it was well – suited for X-ray structural analyses . Observed NOEs in solution were confirmed in solid state by determination of H-4...H-18 and H-8...H-14 distances, 3.0429 and 3.4333 A, respectively. There is an intramolecular hydrogen bond between N-H and P=O (O-1...H-1 distance of 2.091 A and angel of 149.8° was found) (Figure 1 and 2) .

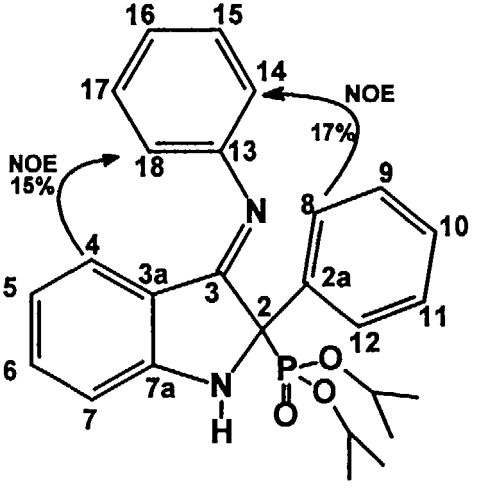


FIGURE 1 Numbering of one stereoisomer of rac-**3** with observed NOEs

Additionally we found that molecules in crystals are aggregated as dimers through two intermolecular H-bonds (Figure 3).

To find the rational explanation for the course of the reaction in focus we run a set of experiments with the different ratio of nitrone **1** to >P-O$^-$ anion. The results of this experiments are collected in Table I.

TABLE I Reaction of nitrone **1** with sodium diisopropylphosphite

Run	*Ratio 1:PO$^-$*	*Conditions*	*Yield [%]*		
			1	*2*	*3*
1	1:1.1	THF, RT, 2 h	32	29	39
2	1:1.5	THF, RT, 2 h	6	41	53
3	1:1.8	THF, RT, 2 h	-	36	64
4	1:3	THF, RT, 2 h	-	-	100

PO$^-$ = sodium diisopropylphosphite.

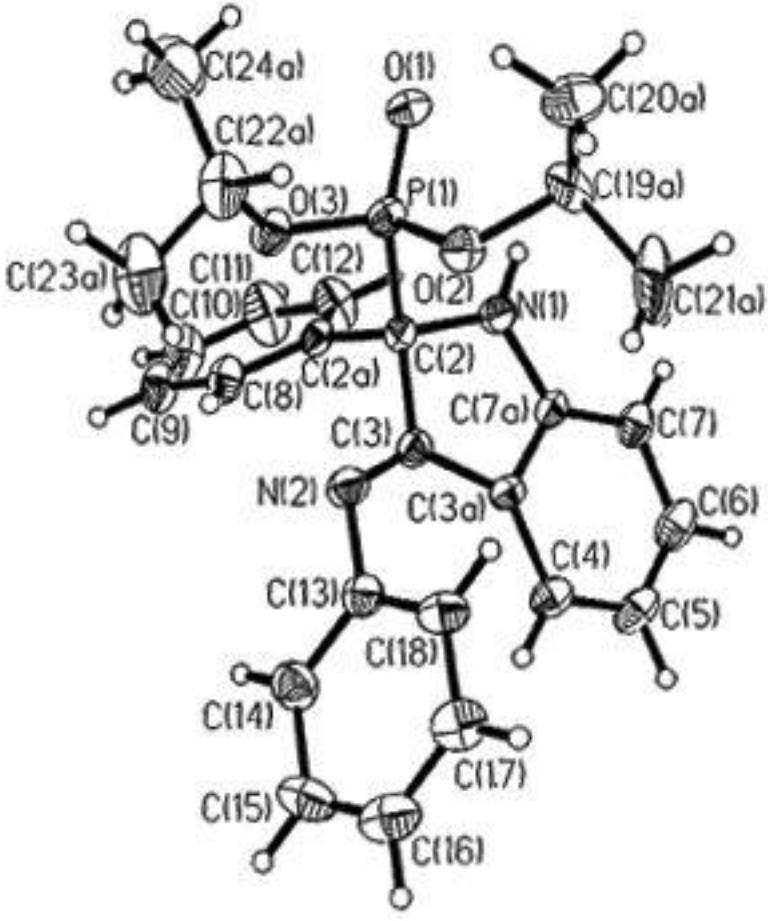


FIGURE 2 ORTEP drawing of 3

The examination of the data in this table reveals that the product distribution of the reaction under investigation, strongly depends on the ratio of nitrone **1** to diisopropyl phosphite anion. The yield of the aminophosphonate **3** increases with the increase of the concentration of the >P-O⁻ reagent in the reaction mixture. Furthermore, we have not observed the addition product of the diisopropyl phosphite anion into the nitrone C=N double

bond, namely α-N-hydroxyaminophosphonate[14], as well as the addition product of the >P-O⁻ reagent into C=N double bond of the N-phenylimine moiety, in the reaction mixture.

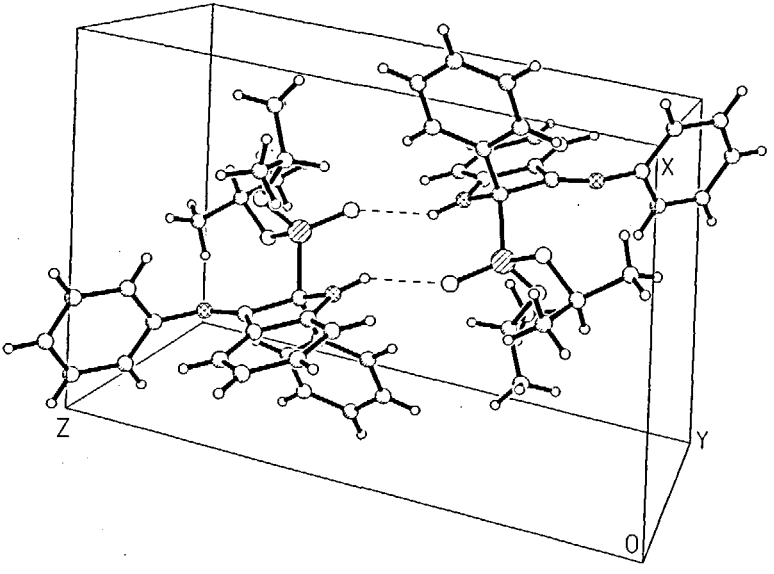
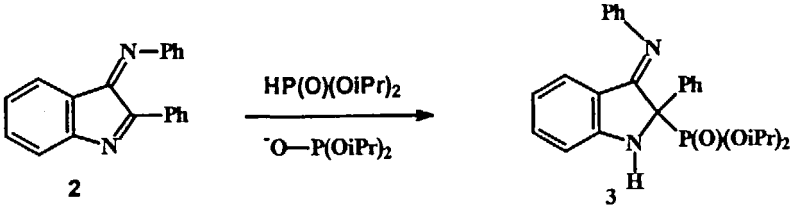


FIGURE 3 Stereopacking of 3 in the unit cell showing intermolecular H-bonds (as broken lines)

Taking into consideration the isolation of aminophosphonate **3** from the reaction mixture of nitrone **1** with sodium diisopropylphosphite, one can conclude that the reduction of nitrone **1** by the >P-O⁻ anion into imine **2** is the first step of the reaction under investigation, that the second step would be the nucleophilic addition of the >P-O⁻anion into the C=N *endo* double bond of the imine **2** to yield, after work up, aminophosphonate **3**.

To check this hypotheses first of all we had to prove, that imine **2** is capable to react with dialkyl phosphites in the sense of nucleophilic addition. This expectation was verified by experimentation. We carried out the reaction of 1 equiv. of imine **2** with diisopropyl phosphite in the presence of different amounts of sodium diisopropyl phosphite or DBU (as a basic catalyst) in THF and i-PrOH as the solvents (Scheme 3). The results of this set of experiments are collected in Table II.



SCHEME 3

TABLE II Reaction of imine 2 with diisopropyl phosphite

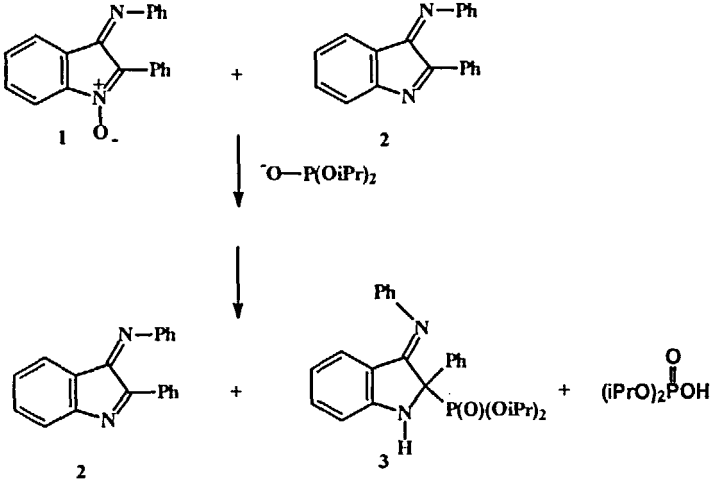
Run	*Reagents*	*Ratio 2: reagents*	*Conditions*	*Yield [%]*	
				2	*3*
1	POH	1:1	THF, RT, 16 h	100	-
2	POH	1:2.2	THF, reflux, 2h	94	6
3	POH, DBU	1 :1 :0.3	THF, RT, 1.5 h, dark	81	9
4	POH, DBU	1:1:0.3	THF, RT, 1.5 h, daylight	81	9
5	POH, DBU	1:1:0.2	THF, RT, 21 h	60	32
6	POH, DBU	1:1:0.4	THF, RT, 21 h	40	52
7	POH, DBU	1:1:1.1	THF, RT, 21 h	5	87
8	PO^-	1:1	THF, RT, 2 h	13	87
9	PO^-	1:1.2	THF, RT, 2 h	5	95
10	PO^-	1:1.1	iPrOH, RT, 2 h	13	87
11	PO^-	1:1.6	iPrOH, RT, 2 h	-	100
12	POH, PO^-	1:1:0.05	THF, RT, 5 min., daylight	-	100
13	POH, PO^-	1:1:0.05	THF, RT, 3 min., dark	-	100
14	POH, PO^-	1:1:0.1	THF, –70°C, 5 min.	57	43
15	POH, PO^-	1:1:0.1	THF, –70°C, 10 min.	10	90
16	POH, PO^-	1:1:0.1	THF, –70°C, 20 min.	-	100

PO^- = sodium diisopropylphosphite, POH = diisopropyl phosphite,
DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene.

As one can see from the data presented in the Table II, diisopropyl phosphite undergoes nucleophilic addition into imine 2 to yield aminophosphonate 3 in the presence of catalytic amounts of sodium diisopropyl phosphite already at –70°C (Table II runs 12 – 16). DBU, on the other

hand, appears to be a less efficient basic catalyst for this reaction (Table II runs 3 – 7). Moreover, no influence of light on the course of the reaction in focus has been observed (Table II runs 3,4 and 12, 13).

Additionally, we run a competition experiment, i.e., we treated the mixture composed of 1 equiv. of nitrone **1** and 1 equiv. of imine **2** with sodium diisopropyl phosphite. From this reaction mixture we isolated two products, namely, imine **2** and aminophosphonate **3** (Scheme 4; Table III). The comparison of the yields of these two products strongly suggests that the rate of the nitrone **1** deoxygenation is faster than the rate of nucleophilic addition of the phosphite into the C=N double bond of imine **2** but they seem to be of the same order of magnitute.



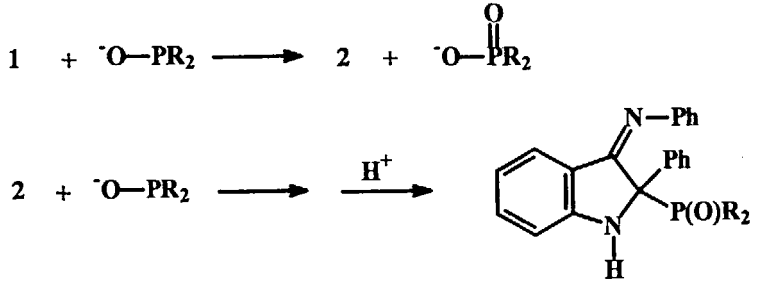
SCHEME 4

TABLE III Relative reactivities of **1** and **2** towards diisopropyl phosphite Competition experiments

Run	*Ratio 1:2: PO⁻*	*Yield [%]*		
		1	*2*	*3*
1	1:1:1	34	154	12
2	1:1:2	0	154	46
3	1:1:8	-	-	100

PO^- = sodium diisopropylphosphite.

We also investigated the reaction mixture of the nitrone **1** with sodium diisopropyl phosphite employing ^{31}P NMR spectroscopy. The spectrum shows two resonance lines responsible for two phosphorus products of this reaction, which we identified as being: aminophosphonate **3** ($\delta = +16{,}3$ ppm) and diisopropyl phosphate ($\delta = -5{,}0$ ppm). Evidence obtained from ^{31}P NMR spectroscopic studies confirms our postulate of the reduction of nitrone **1** by the >P-O$^-$ anion into imine **2** being the principal process in our proposed mechanism and the following nucleophilic addition of the phosphite into the C=N double bond of the imine **2** (Scheme 5).



SCHEME 5

At this stage of our research we can conclude, that dialkyl phosphite anion is consumed in the redox reaction with nitrone **1**, but the dialkyl phosphate produced in this reaction, is not a good enough nucleophile to be able to add into the C=N double bond of the imine **2**. This is the reason why we obtained a quantitative yield of the aminophosphonate **3** in the case when the >P-O$^-$ reagent was used in the amount higher than 2 equivalents.

To answer the question what is the reductant of the nitrone **1**, in separate experiment we treated 1 equiv. of nitrone **1** with diisopropyl phosphite in the absence of any basic catalyst in THF and benzene at room temperature as well as at the boiling point of the solvents. In every one of these experiments we isolated starting materials only. The results of this set of experiments show that under these conditions dialkyl phosphites are not able to reduce nitrone **1**. We also treated the nitrone **1** with triisopropyl phosphite; from this reaction mixture we isolated imine **2** as a main product. Additionally, the ^{31}P NMR spectrum of this reaction mixture showed the signal responsible for the presence of the triisopropyl phosphate ($\delta = -2.9$ ppm).

Indeed, deoxygenation of nitrones can be performed by triphenylphosphine and leads to the corresponding imine[15], and recently Tordo[16] has been able to demonstrate that tris(trimethylsilyl)phosphite reduces 5,5-dimethyl-2,4-diphenylpyrroline N-oxide. On the basis of the results of our experiments, as well as the literature data, one can conclude, that ketonitrones suffer deoxygenation under the action of the three coordinated phosphorus reagents.

Dialkyl phosphites exist almost entirely in the phosphonate form $(RO)_2P(O)H$, which bears no lone pair electrons on phosphorus. Accordingly, the neutral esters are unreactive partners in nucleophilic substitution reactions, as well as deoxygenation reactions, compared with trialkylphosphites. The >P-O$^-$ anions in the presence of lithium, sodium and potassium cations however, exist almost entirely in the phosphite form (three coordinated phosphorus, which bears a lone pair of electrons) which has been established with reliability by ^{31}P NMR spectroscopy. The ^{31}P NMR shift values for the alkali metal salts of dialkyl phosphites, have been found in the range from 139 to 153 ppm which corresponds to the ^{31}P NMR shift values found in phosphite structure[17].

To check the scope and limitation of the reduction power of the >P-O$^-$ reagents toward nitrones, we have decided to study other aldo – as well as keto-nitrones possessing wide range of substituents. This work is in progress and the results will be published successively.

EXPERIMENTAL

Dialkyl phosphites were purchased from Aldrich and distilled before use. Sodium hydride (Aldrich) was washed with hexane to remove paraffin oil. Tetrahydrofuran was dried with sodium-potassium alloy. Isopropanol was dried with calcium hydride. Benzene was dried over sodium. TLC were carried out using Merck Kieselgel 60 F 254 plates (system A: chloroform-methanol 10:1, system B: ethyl acetate-hexane 1:2). Melting points were uncorrected.

NMR spectra were obtained on a Varian apparatus operating at 500 MHz (^1H), 126 MHz (^{13}C) and 202 MHz (^{31}P). Unambiguous assignments for all proton and carbon resonances were achieved on basis of HMBC[18], HMQC[19], COSY and NOE-difference experiments. Mass spectra were

obtained on a AMD 604 spectrometer. UV spectra were obtained in THF on a Perkin Elmer Lambda Bio UV/VIS spectrophotometer.

Nitrosobenzene[20], 1-hydroxy-2-phenylindole[21] and 2-phenylindole[21] were prepared according to the methods described in the literature.

2-Phenyl-3-phenylimino-3*H*-indole 1-oxide 1

Was obtained by reaction of 1-hydroxy-2-phenylindole with nitrosobenzene[7a] in dry methanol in 96% yield, mp 206–208°C (lit. 7a mp 210–212°C), R_f (A) 0.95, R_f (B) 0.69

^{1}H NMR ($CDCl_3$) δ = 6.55 (d, J=7.3, H-4, 1H), 7.04 (dd, J=7.4, J=1.5, H-14/18, 2H), 7.20 (dt, J=7.4, J=1, H-5, 1H), 7.30 (t, J=7.4, H-16, 1H), 7.48 (t, J=7.8, H-15/17, 2H), 7.50 (t, H-10, 1H), 7.56 (2xt, H-9/11 and H-6, 3H), 7.82 (d, J=7.8, H-7, 1H), 8.65 (dd, J=7.4, J=1.5, H-8/12, 2H)

Positive NOEs between H-14/18 and H-4 (23%) confirmed (Z)-configuration of **1** as Greci found out previously by X-ray and HPLC analysis[22].

2-Phenyl-3-phenylimino-3*H*-indole 2

Was obtained by reaction of 2-phenylindole with nitrosobenzene in ethanol[23] in 70% yield, mp 153–154°C (lit.[23] mp 155°C), R_f (A) 0.95, R_f (B) 0,78

^{1}H NMR ($CDCl_3$) δ = 6.59 (d, J=7.3, H-4, 1H), 6.94 (dt, J=7.8, J=1, H-5, 1H), 7.04 (dd, J=7.4, J=1, H-14/18, 2H), 7.30 (dt, J=7.4, J=1, H-16, 1H), 7.40 (dt, J=7.4, J=1, H-6, 1H), 7.48

(t, J=7.8, H-15/17, 2H), and H-10, 3H), 7.50–7.55 (m, H-9/11, H-7, H-10, 4H), 8.46 (dd, H-8/12, 2H)

Positive NOEs between H-14/18 and H-4 (7.7%) confirmed (Z)-configuration of **2**.

The Reaction between Nitrone 1 and Sodium Diisopropylphosphite

To a suspension of NaH (0.1 g, 4.2 mmol) in 24 mL of THF diisopropyl phosphite (0.65 g, 3.9 mmol) was added. When the evolution of hydrogen had ceased, 0.68 mL (0.11 mmol) of thus obtained sodium diisopropyl phosphite solution was introduced into a stirred solution of nitrone **1** (0.03 g, 0.1 mmol) in 2 mL of THF, at room temperature under argon.

After 2 hrs the reaction mixture was quenched with a 5% aqueous NH_4Cl solution (0.5 mL). The resulting mixture was extracted with 15 mL of ethyl acetate. The organic phase was washed with water (2 × 3 mL), brine, and dried over $MgSO_4$. The solvent was removed under vacuum to yield a mixture of three compounds which were identified by TLC and ^1H NMR (comparision with authentic samples). The yields of **1, 2** and **3** were determined on the basis of relative peak intensities at 8.65, 8.46 and 8.12 ppm (^1H NMR), respectively.

The aforementioned experiment was repeated with different ratios of **1/PO$^-$**, and the results are summarised in Table I.

Run 4

To a stirred orange solution of **1** (0.298 g, 1 mmol) in dry THF (20 mL), 18.5 mL (3 mmol) of sodium diisopropylphosphite solution in THF (0.1625 M) were added via syringe, under an argon atmosphere at room temperature. The reaction mixture turned deep purple within 1 minute, with the resulting colour being unchanged (λ_{max} 510 nm). After 2 hrs the reaction mixture was quenched by the addition of a 5% aqueous NH_4Cl solution (10 mL). The resulting light-yellow mixture was extracted with ethyl acetate (3 × 10 mL). The organic phase was washed with water (2 × 10 mL), brine and dried over $MgSO_4$. The solvents were distilled off under vacuum to yield 0.5 g of a crude product. Purification by radical chromatography on silica gel (chloroform:methanol = 50:1), followed by crystallisation from benzene-hexane gave 0.343 g (76%) of a pure 1,2-dihydro-2-(diisopropoxyphosphoryl)- 2-phenyl-3-phenylimino-3*H*-indole **3** as light-yellow crystals, mp 168–170°C, R_f (A) 0.60, R_f (B) 0.25, ^{31}P NMR δ 16.3 ppm

HRMS: calc. for $C_{26}H_{29}N_2O_3P$ 448.19158, found 448.191071; reference mass: 442.972851

MS (EI, 70eV, 8kV): 449 (M+1, 4%), 448 (M, 15%), 406 (M-iPr, 6%), 364 (M-2iPr, 25%), 283 [M-P(O)(OiPr)$_2$, 100%], 206 [M-P(O)(OiPr)$_2$-C_6H_5, 10%]

UV (λ_{max} 385 nm and λ_{max} 264 nm)

TABLE IV ^{1}H and ^{13}C NMR Data for compound **3**, δ ppm with respect to internal TMS

Position	*Chemical Shift (δ) ppm*		*Long-Range Coupling Pathways*[a] *(HMBC spectrum)*
	^{1}H	^{13}C	
2	-	71 (d, J=151 Hz, 4%)	H-8/12
2a	-	137.1 (9%)	H-9/11
3	-	166.5 (3%)	H-4 (weak)
3a	-	118.8 (5%)	H-5
4	6.40 (d, 1H, J=7.8 Hz)	117.9 (35%)	H-6
5	6.41 (t, 1H, J=7.8 Hz)	127.0 (42%)	-
6	7.20 (t, 1H, J=7.8 Hz)	133.5 (4%)	H-4
7	6.89 (d, 1H, J=7.8 Hz)	111.5 (24%)	H-5
7a	-	156.5 (5%)	H-6
8/12	8.12 (dd, 2H, J=7.4 Hz, J=1 Hz)	127.52/127.56 (58%)	H-10
9/11	7.41 (t, 2H, J=7.4 Hz)	127.9 (66%)	-
10	7.35 (t, 1H, J=7.4 Hz)	127.7 (29%)	H-8/12
13	-	151.9 (3%)	H-15/17
14/18	6.90 (d, 2H)	118.30/118.34 (26%)	H-16
15/17	7.35 (t, 2H)	129.4 (100%)	-
16	7.15 (t, 1H)	123.1(16%)	H-14/18
CH_3-CH	0.95 (d, 3H), 1.15 (d, 3H), 1.30 (d, 3H), 1.35 (d, 3H)	24.5 (35%), 23.9 (32%), 23.6 (28%), 23.0 (31%)	-
CH_3-CH	4.72 (sep, 2H)	72.9 (14%), 72.7 (15%)	-
N-H	5.45 (br s)	-	-

[a] From the proton specified in the column to the carbon located at the indicated position in the molecular structure.

X-ray determination

Intensity data were collected on a Kuma KM4 diffractometer with a graphite monochromator using MoK radiation. The cell parameters were calculated by least squares from the setting angles of 25 reflections. Three reference reflections were measured in the interval of 100 measured

reflections. Total decay of measured intensities was 35.2%. The data were corrected for Lp but not for absorption and secondary extinction. The unique set of 4687 measured data up to 2=54 were used for refinement.

TABLE V Crystal data and structure refinement for 1,2-dihydro-2-(diisopropoxy-phosphoryl)-2-phenyl-3-phenylimino-3*H*-indole **3**

Identification code	**3**
Empirical formula	$C_{26}H_{29}N_2O_3P$
Formula weight	448.48
Temperature	293(2) K
Wavelength	0.71073 A
Crystal system, space group	triclinic, $P\bar{1}$
Unit cell dimensions	a = 9.128(6) Å α = 84.72(2) deg. b = 9.765(2) Å β = 79.82(8) deg. c = 14.295(4) Å γ = 80.46(7) deg.
Volume	1234.2(9) $Å^3$
Z, Calculated density	2, 1.207 Mg/m^3
Absorption coefficient	0.140 mm^{-1}
F(000)	476
Crystal size	0.50 × 0.30 × 0.20 mm
Theta range for data collection	1.45 to 27.00 deg.
Index ranges	-11 <=h<=11 −12<=k<=12, 0<=1<=18
Reflections collected / unique	4870 / 4687 [R(int) = 0.0617]
Completeness to 2theta = 27.00	86.8%
Max. and min. Transmission	0.9592 and 0.9461
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	4687 / 16 / 348
Goodness-of-fit on F^2	0.973
Final R indices [I>2sigma(I)]	R1 = 0.0805, wR2 = 0.1447
R indices (all data)	R1 = 0.2122, wR2 = 0.1854
Largest diff. peak and hole	0.176 and −0.234 e.A^-3

The structure was solved with direct methods using program SHELXS[24] and refined using SHELX-97[25]. Heavy atoms were refined with individual anisotropic temperature factors. Hydrogen atoms were found in difference Fourier map (except that at isopropyl groups) and refined in idealized positions with isotropic temperature factors U calculated as 1.2 times the equivalent isotropic temperature factors U of the preceding carbon atoms. For both disordered ester groups common values (within esds' of 0.005) were refined for C-O bonds, C-C bonds and 1–3 C-C contacts. Occupancy factors for more occupied position of both disordered isopropyl groups converged at 0.62. Full matrix weighted least-squares refinement against F-squared were performed [function minimized: $\Sigma w(Fo2\text{-}Fc2)2$ with w-1=σ2(Fo2)+(0.0707xP)2 where P=(Max(Fo2,0)+2Fc2)/3]. The final discrepancy factors were: $R1$=0.0805 and $wR2$=0.1447 for observed reflections with F2 > 2sigma(F2) and: $R1$=0.2122, $wR2$= 0.1854 for all data, goodness of fit 0.973. The crystal and final refinemen data are presented in Table V, and the bond angles and the bond distances are summarized in Table VI.

TABLE VI Bond lengths (Å) and angles [deg] for **3**

Å		*deg*	
P(1)-O(1)	1.459(2)	O(1)-P(1)-O(3)	116.03(14)
P(1)-O(3)	1.556(2)	O(1)-P(1)-O(2)	114.59(14)
P(1)-O(2)	1.574(2)	O(3)-P(1)-O(2)	104.20(13)
P(1)-C(2)	1.822(4)	O(1)-P(1)-C(2)	112.71(16)
O(2)-C(19A)	1.483(4)	O(3)-P(1)-C(2)	103.77(15)
O(2)-C(19B)	1.484(4)	O(2)-P(1)-C(2)	104.22(14)
O(3)-C(22A)	1.483(4)	C(19A)-O(2)-P(1)	118.6(2)
O(3)-C(22B)	1.485(5)	C(19B)-O(2)-P(1)	133.1(3)
N(1)-C(7A)	1.376(4)	C(22A)-O(3)-P(1)	127.6(2)
N(1)-C(2)	1.455(4)	C(22B)-O(3)-P(1)	111.6(3)
N(2)-C(3)	1.267(4)	C(7A)-N(1)-C(2)	110.4(3)
N(2)-C(13)	1.407(4)	C(3)-N(2)-C(13)	121.3(3)
C(2)-C(3)	1.531(4)	N(1)-C(2)-C(3)	102.3(2)
C(2)-C(2A)	1.546(4)	N(1)-C(2)-C(2A)	112.5(3)
C(2A)-C(8)	1.364(4)	C(3)-C(2)-C(2A)	110.8(2)

Å		deg	
C(2A)-C(12)	1.365(5)	N(1)-C(2)-P(1)	103.8(2)
C(3)-C(3A)	1.457(4)	C(3)-C(2)-P(1)	112.7(2)
C(3A)-C(7A)	1.383(4)	C(2A)-C(2)-P(1)	114.0(2)
C(3A)-C(4)	1.399(4)	C(8)-C(2A)-C(12)	118.1(3)
C(4)-C(5)	1.379(5)	C(8)-C(2A)-C(2)	120.7(3)
C(5)-C(6)	1.372(5)	C(12)-C(2A)-C(2)	121.1(3)
C(6)-C(7)	1.377(5)	N(2)-C(3)-C(3A)	133.2(3)
C(7)-C(7A)	1.381(5)	N(2)-C(3)-C(2)	120.7(3)
C(8)-C(9)	1.383(5)	C(3A)-C(3)-C(2)	106.1(3)
C(9)-C(10)	1.368(5)	C(7A)-C(3A)-C(4)	119.5(3)
C(10)-C(11)	1.321(5)	C(7A)-C(3A)-C(3)	108.0(3)
C(11)-C(12)	1.386(5)	C(4)-C(3A)-C(3)	132.6(3)
C(13)-C(18)	1.370(5)	C(5)-C(4)-C(3A)	118.4(3)
C(13)-C(14)	1.371(5)	C(6)-C(5)-C(4)	120.7(4)
C(14)-C(15)	1.401(5)	C(5)-C(6)-C(7)	122.2(4)
C(15)-C(16)	1.355(6)	C(6)-C(7)-C(7A)	116.9(3)
C(16)-C(17)	1.353(6)	N(1)-C(7A)-C(7)	126.8(3)
C(17)-C(18)	1.367(5)	N(1)-C(7A)-C(3A)	110.9(3)
C(19A)-C(21A)	1.469(4)	C(7)-C(7A)-C(3A)	122.3(3)
C(19A)-C(20A)	1.471(5)	C(2A)-C(8)-C(9)	121.8(4)
C(22A)-C(23A)	1.469(4)	C(10)-C(9)-C(8)	118.5(4)
C(22A)-C(24A)	1.470(5)	C(11)-C(10)-C(9)	120.4(4)
C(19B)-C(21B)	1.472(5)	C(10)-C(11)-C(12)	121.4(4)
C(19B)-C(20B)	1.475(5)	C(2A)-C(12)-C(11)	119.8(4)
C(22B)-C(23B)	1.470(5)	C(18)-C(13)-C(14)	118.0(3)
C(22B)-C(24B)	1.471(5)	C(18)-C(13)-N(2)	121.0(3)
		C(14)-C(13)-N(2)	120.7(3)
		C(13)-C(14)-C(15)	120.3(4)
		C(16)-C(15)-C(14)	119.1(4)
		C(17)-C(16)-C(15)	121.3(4)
		C(16)-C(17)-C(18)	119.1(4)
		C(17)-C(18)-C(13)	122.0(4)
		C(21A)-C(19A)-C(20A)	111.9(4)

Å	*deg*	
	C(21A)-C(19A)-O(2)	107.3(4)
	C(20A)-C(19A)-O(2)	109.8(4)
	C(23A)-C(22A)-C(24A)	112.1(4)
	C(23A)-C(22A)-O(3)	108.0(4)
	C(24A)-C(22A)-O(3)	106.1(5)
	C(21B)-C(19B)-C(20B)	111.4(5)
	C(21B)-C(19B)-O(2)	105.8(6)
	C(20B)-C(19B)-O(2)	103.4(5)
	C(23B)-C(22B)-C(24B)	111.8(5)
	C(23B)-C(22B)-O(3)	105.8(8)
	C(24B)-C(22B)-O(3)	107.9(6)

The Reaction between Imine 2 and Sodium Diisopropylphosphite (see Table II)

Run 1

To a stirred red-orange solution of **2** (0.028 g, 0.1 mmol) in dry THF (2 mL) diisopropyl phosphite (0.017 mL, 0.1 mmol) was added via syringe, at room temperature under an argon atmosphere. After 16 hrs THF was evaporated. TLC and ^{1}H NMR analysis showed that the reaction mixture contained pure **2**.

The same pocedure was involved in run 2

Runs 3–7

In this set of experiments different amounts of DBU were added to a mixture of **2**(0.028 g, 0.1 mmol) and diisopropyl phosphite (0.017 mL, 0.1 mmol) in dry THF (2 mL) at room temperature under an argon atmosphere. The red-orange color of the reaction mixture was not changed during the course of the experiment. After 21 hrs the reaction mixture was quenched with NH_4Cl solution and worked-up as described above. The yields of **2** and **3** were determined on the basis of relative peak intensities at 8.46 and 8.12 ppm (^{1}H NMR), respectively.

Run 8

0.616 mL (0.1 mmol) of a sodium diisopropyl phosphite solution (0.1623 M) in THF was introduced to a stirred solution of imine **2** (0.028 g, 0.1 mmol) in 2 mL of THF, at room temperature under argon. After 2 hrs the reaction mixture was quenched with a 5% aqueous NH_4Cl solution (0.5 mL). The resulting mixture was extracted with 15 mL of ethyl acetate. The organic phase was washed with water (2 × 3 mL), brine and dried over $MgSO_4$. Solvents were removed under vacuum to yield a mixture of two compounds which were identified by TLC and ^1H NMR (comparision with authentic samples). The yields of **2** and **3** were determined on the basis of relative peak intensities at 8.46 and 8.12 ppm (^1H NMR), respectively. The same pocedure was involved in run 9.

Run 11

To a stirred red-orange solution of **2** (0.141 g, 0.5 mmol) in dry isopropanol (15 mL) 4.7 mL (0.8 mmol, 1.6 equiv.) a solution of sodium diisopropylphosphite in isopropanol (0.176 M) were added via syringe, at room temperature under an argon atmosphere. After 2 hrs the resulting light-yellow clear solution was quenched with a 5% aqueous NH_4Cl solution (5 mL). Work-up and crystallisation as described above afforded 0.19 g (85%) of 1,2-dihydro-2-(diisopropoxyphosphoryl)-2-phenyl-3-phenylimino-3*H*-indole **3** as light-yellow crystals, mp 164–165°C.

The same pocedure was involved in run 10.

Run 12

To a stirred red-orange solution of **2** (0.028 g, 0.1 mmol) in dry THF (2 mL) diisopropyl phosphite (0.017 mL, 0.1 mmol) was added via syringe, at room temperature under an argon atmosphere. Next 0.0175 mL (0.005 mmol) of a solution of sodium diisopropylphosphite in THF (0.293 M) was added. After 5 min. the resulting clear light-yellow solution was quenched with a 5% aqueous NH_4Cl solution (1 mL). TLC and ^1H NMR analysis showed that the reaction mixture contained 1,2-dihydro-2-(diisopropoxyphosphoryl)-2-phenyl- 3-phenylimino -3*H*-indole **3** as the only product.

The aforementioned experiment was repeated at different reaction times at room temperature, as well as at –70°C. The results are summarised in Table II, runs 13–16.

The Reaction of Equimolar Mixture of Nitrone 1 and Imine 2 with Sodium Diisopropylphosphite (see Table III)

0.616 mL (0.1 mmol) of a sodium diisopropyl phosphite solution (0.1623 M) was introduced to a stirred solution of nitrone **1** (0.03 g, 0.1 mmol) and imine **2** (0.028 g, 0.1 mmol) in 4 mL of THF, at room temperature under argon. After 1 hour the reaction mixture was quenched with a 5% aqueous NH_4Cl solution (1 mL). The resulting mixture was extracted with 20 ml of ethyl acetate. The organic phase was washed with water (2 × 5 mL), brine and dried over $MgSO_4$. The solvent was removed under vacuum to yield a mixture of three compounds which were identified by TLC and ^1H NMR (comparision with authentic samples). The yields of **1**, **2** and **3** were determined on the basis of relative peak intensities at 8.65, 8.46 and 8.12 ppm (^1H NMR), respectively.

The aforementioned experiment was repeated with different ratios of starting materials. The results are summarised in Table III, runs 1–3.

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