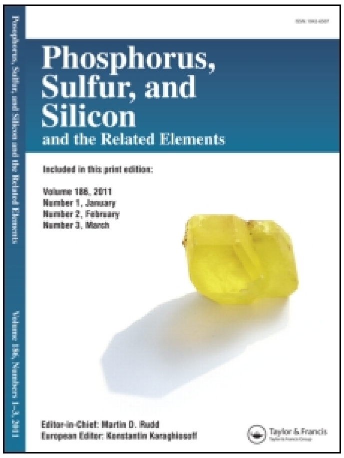

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FUNCTIONALIZATION OF AMINOPHOSPHONIC CHLORIDES AND SYNTHESIS OF PHOSPHORUS HETEROCYCLIC COMPOUNDS

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FUNCTIONALIZATION OF AMINOPHOSPHONIC CHLORIDES AND SYNTHESIS OF PHOSPHORUS HETEROCYCLIC COMPOUNDS

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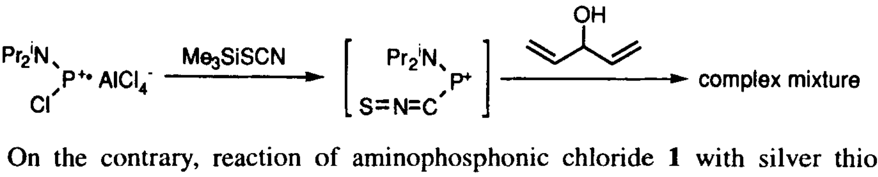
Aminophosphonic chlorides **1–3** reacted with silver thiocyanate to give corresponding isothiocyanates **4–6** in good to moderate yields. Similarly, aminophosphonic chlorides **7–9** reacted with unsaturated alcohols and allylmagnesium bromide to give trienes **15–18** containing phosphorus. An intramolecular Diels-Alder reaction of triene **18** gave isophosphindoline derivative **19**. The conformation of **19** is also discussed.

Key words: Phosphanylium cation, intramolecular Diels-Alder reaction, isophosphindoline.

Recently, we reported the reactions of chloro(diisopropylamino)phosphanylium cation $[(\mathrm{Pr}^i_2\mathrm{N})(\mathrm{Cl})\mathrm{P}]^+[\mathrm{AlCl}_4]^-$ with unsaturated alcohols to form phosphonylated compounds having an unsaturated bond.[1] Furthermore, we reported the reactions of the chloro(diisopropylamino)phosphanylium cation with enopyranoside to form phosphonylated six membered sugars.[2] Phosphorus heterocycles are interesting compounds,[3] and recently Polniaszek and his co-worker reported a convenient method to prepare 1-oxophospholanes.[4] In this paper, we wish to report functionalizations of aminophosphonic chlorides and an alternative procedure for synthesis of isophosphindoline skeletons.

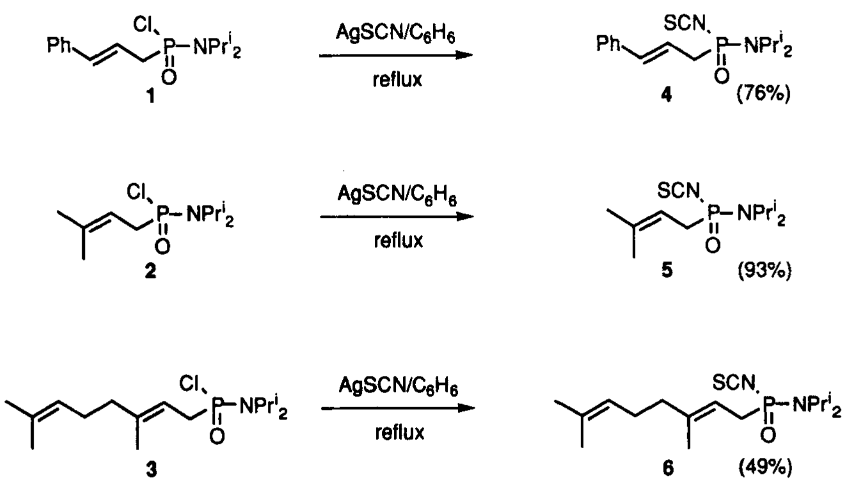
RESULTS AND DISCUSSION

A research group in Toulouse, France, reported functionalization reactions of the phosphanylium cation using chloro(diisopropylamino)phosphanylium cation and silyl compounds.[5–7] However, a reaction of the diisopropylaminoisothiocyanato phosphanylium cation[3] with 1,4-pentadien-3-ol gave a complex mixture[1] (Equation 1).



(eq. 1)

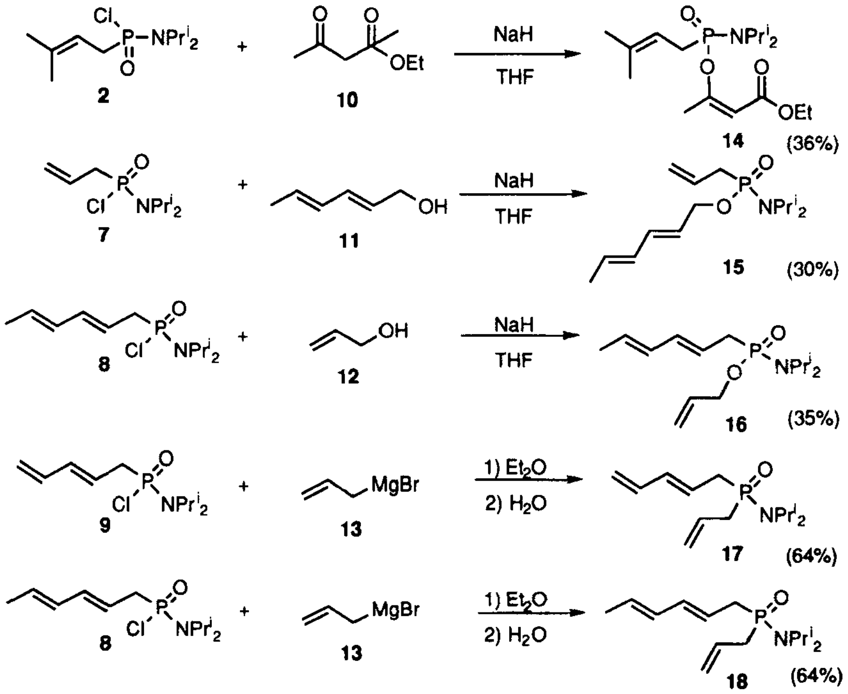
On the contrary, reaction of aminophosphonic chloride **1** with silver thiocyanate in refluxing benzene gave aminophosphonic isothiocyanate derivative **4** in 76%



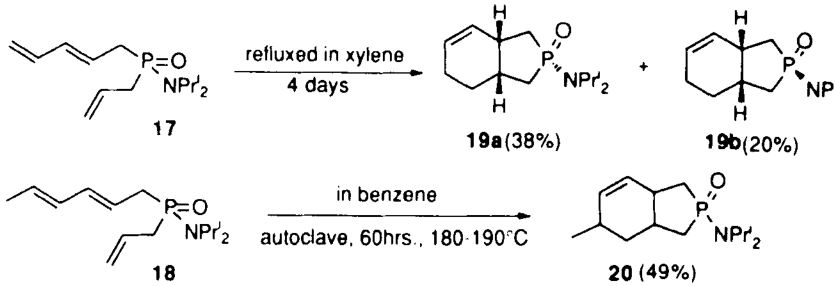
Scheme 1

yield. The structure of the product **4** was determined by spectral data. ^{13}C-NMR spectrum of **4** showed a signal at δ 143.5 ppm which was assigned to an isothiocyanate carbon.[8] Similarly, corresponding aminophosphonic isothiocyanates **5**, **6** were obtained in 93 and 49% yields, respectively.

Furthermore, aminophosphonic chloride **2** reacted with a sodium enolate of ethyl acetoacetate to give **14** in 36% yield. Aminophosphonic chlorides **7** and **8** also reacted with dienylalcohol **11** and allylalcohol **12** in the presence of sodium hydride to give substitution products **15**, **16** in 30% and 35% yields, respectively. Polniaszk



Scheme 2



Scheme 3

et al.[4] reported inter- and intramolecular Grignard reactions of phosphoro chloridates. In the present work, reactions of dienylaminophosphonic chlorides with allyl magnesium bromide gave phosphonic amides **17** and **18** in 64% yield, respectively. The geometries of the products **17** and **18** were determined by ^{1}H-NMR, ^{13}C-NMR, H,H-COSY, and C,H-COSY spectra.

When a solution of compound **17** in xylene was refluxed for 4 days, two products **19a** and **19b** were obtained, after column chromatography, in 38% and 20% yields, respectively. The structures of compounds **19a,b** were determined by spectral data (see experimental section).

Polniaszek[9] reported that ^{31}P-NMR spectra of 1-(N,N,-diisopropylamino)-1-oxo-phospholanes showed signals at −67.7−−70.9 ppm. The ^{31}P-NMR spectra of products **19a** and **b** showed signals at −66.5 and −68.2 ppm, respectively, which were consistent with the Polniaszek's results.

The configuration of the major product **19a** was determined by H,H-NOESY measurement. A positive nuclear Overhauser effect (nOe) was observed between each bridgehead proton, H3a and H7a, but was not observed between bridgehead protons and isopropyl methyne protons (Figure 1).

On the other hand, nOes were observed both between each bridgehead proton and between bridgehead proton H7a and isopropyl methyne protons in the H,H-NOESY spectrum of the compound **19b**. These observations suggest that the configuration of **19a** should be 2R*, 3aR*, 7aS*-form, and that of **19b** should be an epimer of **19a**, i.e. 2S*, 3aR*, 7aS*-form.

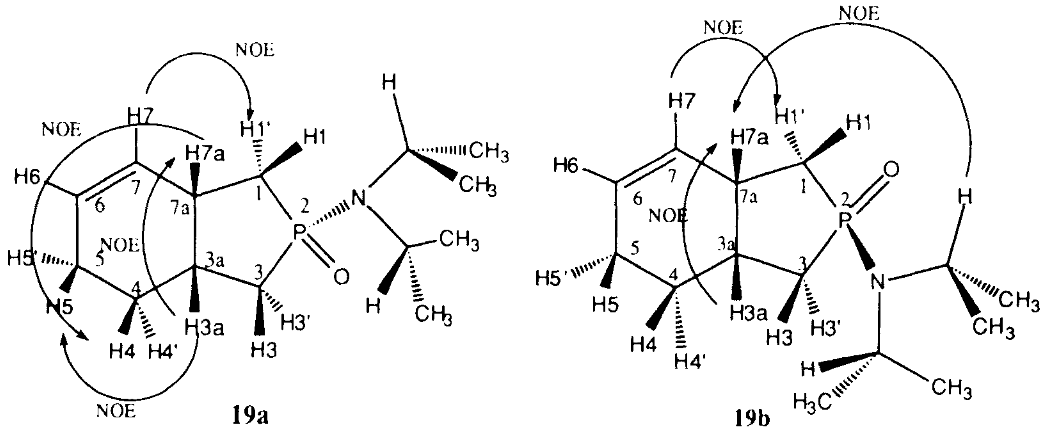


FIGURE 1 H,H-NOESY of **19a** and **19b**.

In an intramolecular Diels-Alder reaction of triene **18** in autoclave at 180–190°C, a diastereomer mixture **20** was obtained in 49% yields. The mixture was separated into three components **20a**, **b**, and **c** in 25%, 1%, and 23% yields, respectively, by column chromatography. These compounds **20a**, **b**, and **c** showed ^{31}P-NMR signals at −68.9 ppm, −62.2 ppm and at −66.2 ppm, along with several minor peaks. In the ^{31}C-NMR and mass spectra of **20a**, **b**, and **c** were consistent with isophosphindoline skeletons. In the ^{1}H-NMR of the **20**, however, bridgehead protons are overlapped with other signals, so that the conformation could not be determined exactly.

EXPERIMENTAL

Melting points were taken with a Yanagimoto micro melting point apparatus. IR spectra were obtained on a JASCO A-100 spectrometer. ^{1}H NMR, ^{13}C NMR and ^{31}P NMR spectra were recorded on JEOL FX-90 and BRUKER DRX-500 spectrometers. ^{1}H and ^{13}C chemical shifts are reported in (δ) ppm from tetramethylsilane and coupling constants are given in Hz; ^{31}P chemical shifts refer to the 85% H_3PO_3 as an external standard. Mass spectra were taken with a JEOL JMS-DX303 spectrometer.

Synthesis of N,N-Diisopropyl-P-(3-phenyl-2-propen-1-yl)phosphonamidic isothiocyanate **4**. A solution of N,N-diisopropylamino-P-(3-phenyl-2-propen-1-yl)phosphonamide chloride **1** (1.34 g, 4.47 mmol) and silver thiocyanate (1.02 g, 5.37 mmol) in dry benzene 20 ml, was stirred for two days at reflux temperature. The salt separated and was removed, and the reaction mixture was concentrated under reduced pressure. Then the residue was purified by column chromatography on silica gel using AcOEt/*n*-hexane (1:1) as an eluent to give a solid, which was recrystallized from hexane to give (1.10 g, 76%) the title compound **4** as a colorless crystalline solid. **4** has m.p.: 78.5–79.2°C; IR (KBr) ν (cm^{-1}): 2980, 2940, 2310, 2010, 1490, 1450, 1410, 1380, 1370, 1240, 1200, 1180, 1150, 1120, 1020, 990, 880, 790, 760, 740 and 690; ^{1}H-NMR (90 MHz, $CDCl_3$): δ 7.43–7.22 (m, 5H, Ph), 6.70–5.97 (m, 2H, —CH═CH—), 3.70–2.78 (m, 4H, NCH, PCH_2), 1.34 (d, 6H, J_{HH} = 6.8 Hz, $NC\underline{CH}_3$), 1.26 (d, 6H, J_{HH} = 7.0 Hz, $NC\underline{CH}_3$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 136.4 (d, $^{3}J_{PC}$ = 15.9 Hz, Ph$\underline{C}$H═CH—), 128.72, 128.67, 128.0, 127.9, 126.6, 126.5 (m, Ph), 118.1 (d, $^{2}J_{PC}$ = 12.1 Hz, PhCH═$\underline{C}$H—), 47.2 (d, $^{2}J_{PC}$ = 4.4 Hz, N$\underline{C}$C), 37.3 (d, $^{1}J_{PC}$ = 124.7 Hz, PC), 23.0 (d, $^{3}J_{PC}$ = 2.2 Hz, NC$\underline{C}$), 22.6 (d, $^{3}J_{PC}$ = 1.7 Hz, NC$\underline{C}$); Anal. Calcd. for $C_{16}H_{23}N_2OPS$: C, 59.61; H, 7.19; N, 8.69, Found: C, 59.68; H, 7.18; N, 8.40.

N,N-Diisopropyl-P-(3-methyl-2-buten-1-yl)phosphonamidic isothiocyanate **5**. In the same way, N,N-diisopropyl-P-(3-methyl-2-buten-1-yl)phosphonamidic chloride **2** (2.21 g, 8.71 mmol) and silver thiocyanate (3.24 g, 17.50 mmol) gave **5** (2.23 g, 93%) as a colorless crystalline solid, m.p.: 30.5–32.2°C; IR (KBr) ν (cm^{-1}): 2980, 2950, 2050, 1460, 1410, 1370, 1260, 1210, 1180, 1160, 1130, 1100, 1030, 1000, 890, 860, 770 and 740; ^{1}H-NMR (90 MHz, $CDCl_3$): δ 5.16–5.26 (m, 1H, —CH═), 2.56–3.59 (m, 4H, NCH, PCH_2), 1.77 (d, 3H, $^{5}J_{PH}$ = 6.6 Hz, CH_3), 1.70 (d, 3H, $^{5}J_{PH}$ = 5.3 Hz, CH_3), 1.33 (d, 6H, J_{HH} = 6.6 Hz, $NC\underline{CH}_3$), 1.26 (d, 6H, J_{HH} = 6.7 Hz, $NC\underline{CH}_3$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 143.4 (s, NCS), 138.3 (d, $^{3}J_{PC}$ = 15.9 Hz, $(CH_3)_2\underline{C}$═CH—), 111.8 (d, $^{2}J_{PC}$ = 11.0 Hz, $(CH_3)_2C$═$\underline{C}$H—), 46.8 (d, $^{2}J_{PC}$ = 4.3 Hz, NC), 32.5 (d, $^{1}J_{PC}$ = 125.7 Hz, PC), 25.8 (d, $^{4}J_{PC}$ = 3.7 Hz, $C(\underline{C}H_3)_2$), 22.9 (d, $^{3}J_{PC}$ = 2.4 Hz, NC$\underline{C}$), 22.4 (d, $^{3}J_{PC}$ = 1.2 Hz, NC$\underline{C}$), 18.3 (d, $^{4}J_{PC}$ = 3.1 Hz, $C(\underline{C}H_3)_2$).

N,N-Diisopropyl-P-(3,7-dimethyl-2,6-octadien-1-yl)phosphonamidic isothiocyanate **6**. In the same way, N,N-diisopropylamino-P-(3,7-dimethyl-2,6-octadien-1-yl)phosphonamidic chloride **3** (0.76 g, 2.38 mmol) and silver thiocyanate (0.80 g, 4.76 mmol) gave **6** (1.10 g, 76%) as a colorless syrup, IR (KBr) ν (cm^{-1}): 2970, 2930, 2030, 1450, 1400, 1370, 1250, 1200, 1180, 1160, 1120, 1080, 1020, 1000, 880, 850 and 750; ^{1}H-NMR (90 MHz, $CDCl_3$); δ 5.12–5.38 (m, 2H, —CH═), 2.59–3.60 (m, 4H, NCH, PCH_2), 1.61–2.09 (m, 13H, —CH_2—, $C\underline{CH}_3$), 1.34 (d, 6H, J_{HH} = 6.4 Hz, $NC\underline{CH}_3$), 1.27 (d, 6H, J_{HH} = 6.6 Hz, $NC\underline{CH}_3$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 141.8 (d, $^{3}J_{PC}$ = 15.1 Hz, $CH_2CH_2\underline{C}(CH_3)$═C—), 131.7 (s, $(CH_3)_2\underline{C}$═), 123.9 (s, $(CH_3)_2C$═$\underline{C}$), 111.5 (d, $^{2}J_{PC}$ = 10.3 Hz, $CH_2CH_2C(CH_3)$═$\underline{C}$—), 46.8 (d, $^{2}J_{PC}$ = 3.9 Hz, NC), 39.8 (d, $^{4}J_{PC}$ = 2.9 Hz, —$\underline{C}H_2C(CH_3)$═CH—), 32.3 (d, $^{1}J_{PC}$ = 126.0 Hz, PC), 26.5 (d, $^{5}J_{PC}$ = 3.4 Hz, —$\underline{C}H_2$—CH_2—), 25.7 (s, $(\underline{C}H_3)_2C$═), 22.9 (d, $^{3}J_{PC}$ = 2.4 Hz, NC$\underline{C}$), 22.3 (d, $^{3}J_{PC}$ = 2.0 Hz, NC$\underline{C}$), 17.7 (s, $(\underline{C}H_3)_2C$═), 16.7 (d, $^{4}J_{PC}$ = 2.9 Hz, —$CH_2C(\underline{C}H_3)$═CH—).

Synthesis of 1-ethoxycarbonyl-1-propen-2-yl N,N-diisopropyl-P-(3-methyl-2-buten-1-yl)phosphonamidate **14**. To the suspension of NaH (60% in oil, 0.18 g, 4.52 mmol) in dry THF 5 ml added dropwise a solution of ethyl acetoacetate **10** (0.49 g, 3.77 mmol) in dry THF 5 ml. The mixture was stirred for 0.5 hr at room temperature and a solution of N,N-diisopropyl-P-(3-methyl-2-buten-l-yl)-phosphanamidic chloride **2** (0.95 g, 3.77 mmol) in dry THF 5 ml was added to the solution. After stirring for 2 hr at room temperature, the mixture was quenched with H_2O and extracted with ether. The combined organic layer was washed with water, dried over Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using AcOEt:*n*-hexane (1/2) as an eluent to give **14** (0.47 g, 36%) as a pale yellow syrup. **14** has IR (KBr) ν (cm^{-1}): 2980, 2940, 1710, 1650, 1440, 1410, 1380, 1380, 1370, 1330, 1250, 1220, 1200, 1180, 1100, 1050, 1020, 980, 880, 860, 770 and 690; ^{1}H-NMR (90 MHz, $CDCl_3$); δ 5.15–5.29 (m, 2H, $\mathrm{POC{=}CH}$, —$\mathrm{CH{=}}$), 4.13 (q, 2H, J_{HH} = 7.0 Hz, —$\mathrm{OC\underline{H}_2CH_3}$), 3.31–3.74 (m, 2H, NCH), 2.66 (m, 2H, $\mathrm{PCH_2}$), 2.24 (s, 3H, $\mathrm{POC(C\underline{H}_3){=}C}$—), 1.70 (m, 6H, —$\mathrm{C(C\underline{H}_3)_2}$), 1.18–1.34 (m, 15H, $\mathrm{NCCH_3}$, $\mathrm{OCH_2C\underline{H}_3}$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 164.3 (s, —$\mathrm{\underline{C}(O)OEt}$), 161.3 (d, $^2J_{\mathrm{PC}}$ = 9.2 Hz, POC), 136.2 (d, $^3J_{\mathrm{PC}}$ = 15.3 Hz, $\mathrm{(CH_3)_2\underline{C}{=}}$), 113.7 (d, $^2J_{\mathrm{PC}}$ = 9.8 Hz, $\mathrm{PC\underline{C}}$), 103.0 (d, $^3J_{\mathrm{PC}}$ = 6.1 Hz, $\mathrm{POC{=}\underline{C}}$), 59.4 (s, —$\mathrm{O\underline{C}H_2CH_3}$), 46.05 (d, $^2J_{\mathrm{PC}}$ = 4.9, NC), 29.4 (d, $^1J_{\mathrm{PC}}$ = 131.8 Hz, PC), 25.8 (d, $^4J_{\mathrm{PC}}$ = 3.1 Hz, $\mathrm{(\underline{C}H_3)_2C{=}}$), 23.5 (d, $^3J_{\mathrm{PC}}$ = 1.2 Hz, NCC), 23.0 (d, $^3J_{\mathrm{PC}}$ = 2.4 Hz, $\mathrm{POC\underline{C}H_3}$), 22.4 (d, $^3J_{\mathrm{PC}}$ = 1.2 Hz, $\mathrm{NC\underline{C}}$), 18.2 (d, $^4J_{\mathrm{PC}}$ = 2.4 Hz, $\mathrm{(\underline{C}H_3)_2C{=}}$), 14.4 (s, —$\mathrm{OCH_2\underline{C}H_3}$).

2,4-Hexadien-1-yl N,N-diisopropyl-P-(2-propen-1-yl)phosphonamidate **15**. In the same way, NaH (60% in oil, 0.099 g, 2.48 mmol), 2,4-hexadien-1-ol **11** (0.22 g, 2.24 mmol), N,N-diisopropyl-P-(2-propen-1-yl)phosphanamidic chloride **7** (0.50 g, 2.24 mmol) gave **15** (0.19 g, 30%) as colorless syrup, IR (neat) ν (cm^{-1}): 2990, 2950, 2890, 1725, 1665, 1640, 1460, 1410, 1375, 1240, 1205, 1180, 1162 and 1124; ^{1}H-NMR (90 MHz, $CDCl_3$): δ 5.46–6.38 (m, 5H, $\mathrm{C\underline{H}{=}C}$), 5.01–5.27 (m, 2H, $\mathrm{C\underline{H}{=}C}$), 4.11–4.70 (m, 2H, $\mathrm{C\underline{H}_2O}$), 3.11–3.61 (m, 2H, $\mathrm{NC\underline{H}}$), 2.55 (dd, 2H, J_{HH} = 7 Hz, J_{PH} = 20 Hz, $\mathrm{PCH_2}$), 1.76 (d, 3H, J_{HH} = 6 Hz, $\mathrm{C\underline{H}_3}$), 1.26 (d, 6H, J_{HH} = 7 Hz, $\mathrm{NCC\underline{H}_3}$), 1.22 (d, 6H, J_{HH} = 7 Hz, $\mathrm{NCC\underline{H}_3}$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 133.4 ($\mathrm{OCH_2CH{=}CHCH{=}\underline{C}H}$—), 130.7 ($\mathrm{OCH_2CH{=}CH\underline{C}H{=}CH}$—), 129.5 ($\mathrm{OCH_2CH{=}\underline{C}H}$—), 129.0 ($\mathrm{OCH_2\underline{C}H{=}}$), 125.6 (d, $^2J_{\mathrm{PC}}$ = 7 Hz, $\mathrm{PCH_2\underline{C}H{=}CH_2}$), 118.9 (d, $^3J_{\mathrm{PC}}$ = 14 Hz, $\mathrm{PCH_2CH{=}\underline{C}H_2}$), 63.5 (d, $^3J_{\mathrm{PC}}$ = 6 Hz, $\mathrm{O\underline{CH}_2CH{=}}$), 45.7 (d, $^2J_{\mathrm{PC}}$ = 5 Hz, NC), 34.7 (d, $^1J_{\mathrm{PC}}$ = 128 Hz, PC), 23.58 (d, $^3J_{\mathrm{PC}}$ = 1 Hz, $\mathrm{NC\underline{C}H_3}$), 23.56 (d, $^3J_{\mathrm{PC}}$ = 1 Hz, $\mathrm{NC\underline{C}H_3}$), 18.0 ($\mathrm{OCH_2CH{=}CHCH{=}CH\underline{C}H_3}$).

2-Propen-1-yl N,N-diisopropyl-P-(2,4-hexadien-1-yl)phosphonamidate **16**. In the same way, NaH (60% in oil, 0.067 g, 1.67 mmol), allyl alcohol **12** (0.097 g, 1.67 mmol) and N,N-diisopropyl-P-(2,4-hexadien-1-yl)phosphanamidic chloride **8** (0.40 g, 1.52 mmol) gave **16** (0.15 g, 35%) as colorless syrup, IR (neat) ν (cm^{-1}): 3030, 2980, 2950, 2890, 1725, 1650, 1625, 1460, 1408, 1380, 1368, 1240, 1208, 1185, 1160, 1125 and 1100; ^{1}H-NMR (90 MHz, $CDCl_3$): δ 5.49–6.16 (m, 5H, —$\mathrm{C\underline{H}{=}C}$—), 5.23–5.39 (m, 2H, $\mathrm{C\underline{H}_2{=}C}$—), 4.12–4.68 (m, 2H, $\mathrm{C\underline{H}_2O}$), 3.08–3.61 (m, 2H, $\mathrm{NC\underline{H}}$), 2.55 (dd, 2H, J_{HH} = 7 Hz, J_{PH} = 20 Hz, $\mathrm{PCH_2}$), 1.72 (d, 3H, J_{HH} = 6 Hz, —$\mathrm{CH{=}CHC\underline{H}_3}$), 1.25 (d, J_{HH} = 7 Hz, $\mathrm{NCC\underline{H}_3}$), 1.21 (d, J_{HH} = 7 Hz, $\mathrm{NCC\underline{H}_3}$); ^{13}C-NMR (22.49 MHz, $CDCl_3$): δ 134.6 (d, $^3J_{\mathrm{PC}}$ = 15 Hz, $\mathrm{OCH_2\underline{C}H{=}}$), 134.0 (d, $^4J_{\mathrm{PC}}$ = 8 Hz, $\mathrm{PCH_2CH{=}CH\underline{C}H{=}}$), 131.3 (d, $^4J_{\mathrm{PC}}$ = 4 Hz, $\mathrm{OCH_2CH{=}\underline{C}H_2}$), 128.2 (d, $^2J_{\mathrm{PC}}$ = 4 Hz, $\mathrm{PCH_2\underline{C}H{=}}$), 121.1 (d, $^3J_{\mathrm{PC}}$ = 11 Hz, $\mathrm{PCH_2CH{=}\underline{C}H}$—), 116.7 (s, $\mathrm{PCH_2CH{=}CHCH{=}\underline{C}H}$—), 63.7 (d, $^2J_{\mathrm{PC}}$ = 6 Hz, $\mathrm{O\underline{C}H_2CH}$), 45.8 (d, $^2J_{\mathrm{PC}}$ = 5 Hz, NC), 33.5 (d, $^1J_{\mathrm{PC}}$ = 128 Hz, PC), 23.6 (d, $^2J_{\mathrm{PC}}$ = 1 Hz, $\mathrm{NC\underline{C}H_3}$), 22.6 (d, $^2J_{\mathrm{PC}}$ = 1 Hz, $\mathrm{NC\underline{C}H_3}$), 18.0 (d, $^6J_{\mathrm{PC}}$ = 2 Hz, $\mathrm{{=}CH\underline{C}H_3}$).

Synthesis of N,N-diisopropyl-P-(2-propen-1-yl)-P-(2,4-pentadien-1-yl)phosphonamide **17**. A solution of allylbromide (0.83 g, 6.81 mmol) in anhydrous ether 20 ml was added dropwise to a stirred solution of magnesium (0.17 g, 6.81 mmol) in anhydrous ether 10 ml under nitrogen, and the mixture was stirred for 3 hr at reflux temperature. After cooling to room temperature, N,N-diisopropyl-P-(penta-2,4-dien-1-yl)phosphonamidic chloride **9** (1.00 g, 4.00 mmol) in anhydrous ether 10 ml was added dropwise to the mixture and the resulting mixture was stirred for 3 hr at room temperature. The mixture was quenched with H_2O and extracted with ether. The combined organic layer was washed with brine, dried over Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chlomatography on silica gel using AcOEt as an eluent to give **17** (0.65 g, 64%) as a colorless syrup. **17** has; IR ν (neat) (cm^{-1}): 2980, 2950, 1640, 1460, 1400, 1370, 1200, 1180, 1160, 1020, 990, 910, 880, 820 and 720; ^{1}H-NMR (500 MHz, $CDCl_3$): δ 6.34 (ddd, 1H, J_{H4H5} = 17.0 Hz, J_{H4H5} = J_{H3H4} = 10.2 Hz, $\mathrm{CH_2{=}C\underline{H}CH{=}CHCH_2P}$), 6.14 (m, 1H, $\mathrm{CH_2{=}CHC\underline{H}{=}CHCH_2P}$), 5.92 (m, 1H, $\mathrm{CH_2{=}C\underline{H}CH_2P}$), 5.79 (ddt, 1H, J_{H2H3} = 14.6 Hz, $^3J_{\mathrm{PH}}$ = J_{H1H2} = 7.4 Hz, $\mathrm{CH_2{=}CHCH{=}C\underline{H}CH_2P}$), 5.16 (m, 2H, $\mathrm{C\underline{H}_2{=}CHCH_2P}$), 5.08 (m, 2H, $\mathrm{C\underline{H}_2{=}CHCH{=}CHCH_2P}$), 3.27 (m, 2H, $\mathrm{NC\underline{H}}$), 2.67–2.51 (m, 4H, $\mathrm{C\underline{H}_2P}$), 1.26 (d, 6H, J_{HH} = 6.6 Hz, CH_3), 1.24 (d, 6H, J_{HH} = 6.6 Hz, CH_3); ^{13}C-NMR (125.8 MHz, $CDCl_3$): δ 136.6 (d, $^4J_{\mathrm{PC}}$ = 4.0 Hz, $\mathrm{CH_2{=}\underline{C}HCH{=}CHCH_2P}$), 135.2 (d, $^3J_{\mathrm{PC}}$ = 12.3 Hz, $\mathrm{CH_2{=}CH\underline{C}H{=}CHCH_2P}$), 129.2 (d, $^2J_{\mathrm{PC}}$ = 8.8 Hz, $\mathrm{CH_2{=}\underline{C}HCH_2P}$), 124.8 (d, $^2J_{\mathrm{PC}}$ = 9.8 Hz, $\mathrm{CH_2{=}CHCH{=}\underline{C}HCH_2P}$), 119.3 (d, $^3J_{\mathrm{PC}}$ = 11.8 Hz, $\mathrm{\underline{C}H_2{=}CHCH_2P}$), 116.2 (d, $^5J_{\mathrm{PC}}$ = 3.4 Hz, $\mathrm{\underline{C}H_2{=}CHCH{=}CHCH_2P}$), 46.0 (d, $^2J_{\mathrm{PC}}$ = 4.5 Hz, $\mathrm{\underline{C}N}$), 36.5 (d, $^1J_{\mathrm{PC}}$ = 79.6 Hz, PC), 35.2 (d, $^1J_{\mathrm{PC}}$ = 79.4 Hz, PC), 23.4 (d, $^3J_{\mathrm{PC}}$ = 10.7 Hz, $\mathrm{NC\underline{C}}$); ^{31}P-NMR (202.5 MHz, $CDCl_3$): δ −43.3; MS m/z 256 ($M^+ + 1$); HRMS (Fab); Calcd. for $C_{14}H_{27}ONP$: M + 1, 256.1830, Found: $M^+ + 1$, 256.1867.

N,N-Diisopropyl-P-(2-propen-1-yl)-P-(2,4-hexadien-l-yl)phosphonamide **18**. In the same way, allylbromide (0.46 g, 3.8 mmol), magnesium (0.19 g, 7.6 mmol) and N,N-diisopropyl-P-(2,4-hexadien-l-yl)phosphonamidic chloride **8** (0.60 g, 2.28 mmol) gave **18** (0.39 g, 64%) as a colorless crystalline solid. **18** has; IR (KBr) ν (cm^{-1}): 2920, 2350, 2150, 1620, 1390, 1340, 1160, 1140, 970, 890, 860, 800, 740 and 690; ^{1}H-NMR (90 MHz, CDCl$_3$): δ 6.16–5.72 (m, 5H, $—CH{=}$), 5.64–5.12 (m, 2H, $CH_2{=}$), 3.44–3.10 (m, 2H, $—CH—(CH_3)_2$), 2.65 (d, 2H, J_{HH} = 7.0 Hz, $—CH_2—$), 2.48 (d, 3H, J_{HH} = 7.3 Hz, $—CH_2—$), 1.78–1.69 (m, 3H, $—CH_3$), 1.25 (d, 12H, J_{HH} = 6.8 Hz, $NCC\underline{H}_3$); ^{13}C-NMR (22.49 MHz, CDCl$_3$): δ 134.7 (d, $^{3}J_{PC}$ = 13.7 Hz, $CH_3CH{=}CH\underline{C}H{=}CHCH_2P$), 131.2 (d, $^{5}J_{PC}$ = 3.9 Hz, $CH_3\underline{C}H{=}CHCH{=}CHCH_2P$), 129.4 (d, $^{2}J_{PC}$ = 8.8 Hz, $CH_2{=}\underline{C}HCH_2P$), 128.4 (d, $^{4}J_{PC}$ = 3.4 Hz, $CH_3CH{=}\underline{C}HCH{=}CHCH_2P$), 121.2 (d, $^{2}J_{PC}$ = 9.8 Hz, $CCH{=}\underline{C}HCH_2P$), 119.1 (d, $^{3}J_{PC}$ = 11.7 Hz, $\underline{C}H_2{=}CHCH_2P$), 46.0 (d, $^{2}J_{PC}$ = 4.4 Hz, NC), 36.4 (d, $^{1}J_{PC}$ = 79.6 Hz, PC), 35.3 (d, $^{1}J_{PC}$ = 80.1 Hz, PC), 23.41 (d, $^{2}J_{PC}$ = 1.5 Hz, $NC\underline{C}$), 23.35 (d, $^{2}J_{PC}$ = 1.5 Hz, $NC\underline{C}$), 18.0 (d, $^{6}J_{PC}$ = 1.0 Hz, $\underline{C}H_3CH{=}CH—$); MS m/z 270 (M$^+$ + 1); HRMS (Fab); Calcd. for $C_{15}H_{20}ONP$: M + 1, 270.1987, Found: M$^+$ + 1, 270.2003.

Synthesis of 2-(N,N-Diisopropylamino)-2-oxo-3a,4,5,7a-tetrahydro isophosphindoline **19**. A solution of N,N-diisopropyl-P-(2-propen-1-yl)-P-(2,4-pentadien-1-yl)phosphonamide **17** (0.9 g, 3.52 mmol) in xylene 15 ml was stirred for 4 days at 140°C. The reaction mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using AcOEt as an eluent to give the title compound **19a** (0.34 g, 38%) as a colorless syrup and **19b** (0.18 g, 20%) as yellow syrup, respectively.

(2R, 3aR*, 7aS*)-2-(N,N-Diisopropylamino)-2-oxo-3a,4,5,7a-tetrahydro isophosphindoline* **19a**: IR (neat) ν (cm^{-1}): 2970, 2940, 1650, 1460, 1400, 1370, 1200, 1180, 1150, 1060, 1020, 990, 880, 780 and 720; ^{1}H-NMR (500 MHz, CDCl$_3$): δ 5.72 (ddt, 1H, J_{H6H7} = 10.0 Hz, J_{H5H6} = 3.7 Hz, $^{5}J_{H6H7a}$ = 2.3 Hz, H6), 5.55 (ddd, 1H, J_{H6H7} = 10.0 Hz, J_{H7H7a} = 5.3 Hz, $^{5}J_{H5H7}$ = 2.1 Hz, H7), 3.37 (m, 2H, $NC\underline{H}$), 2.92–2.83 (m, 1H, H7a), 2.56–2.47 (m, 1H, H3a), 2.06–2.02 (m, 2H, H5), 2.02 (m, 1H, $^{2}J_{PH}$ = 15.5 Hz, J_{H1H7a} = 8.1 Hz, J_{gem} = 1.1 Hz, H1), 1.85 (m, 1H, $^{2}J_{PH}$ = 15.4 Hz, J_{H3H3a} = 7.7 Hz, J_{gem} = 0.9 Hz, H3), 1.73–1.67 (m, 1H, H4), 1.65–1.53 (m, 3H, H1′, H3′, H4′), 1.26 (d, 6H, J_{HH} = 6.7 Hz, CH$_3$), 1.25 (d, 6H, J_{HH} = 6.7 Hz, CH$_3$); ^{13}C-NMR (125.8 MHz, CDCl$_3$): δ 130.1 (d, $^{3}J_{PC}$ = 9.3 Hz, C7), 127.1 (s, C6), 45.9 (d, $^{2}J_{PC}$ = 2.4 Hz, NC), 35.4 (d, $^{2}J_{PC}$ = 11.1 Hz, C7a), 33.8 (d, $^{1}J_{PC}$ = 81.0 Hz, C1), 33.4 (d, $^{2}J_{PC}$ = 9.9 Hz, C3a), 31.5 (d, $^{1}J_{PC}$ = 81.0 Hz, C3), 25.4 (d, $^{3}J_{PC}$ = 9.7 Hz, C4), 23.1 (d, $^{3}J_{PC}$ = 1.9 Hz, $NC\underline{C}$), 22.9 (d, $^{3}J_{PC}$ = 1.8 Hz, $NC\underline{C}$), 22.3 (s, C5); ^{31}P-NMR (202.5 MHz, CDCl$_3$): δ −66.5; MS m/z 256 (M$^+$ + 1); HRMS (Fab): Calcd. for $C_{14}H_{27}ONP$: M + 1, 256.1830, Found: M$^+$ + 1, 256.1845.

(2S, 3aR*, 7aS*)-2-(N,N-Diisopropylamino)-2-oxo-3a,4,5,7a-tetrahydro isophosphindoline* **19b**: IR (neat) ν (cm^{-1}): 2980, 2940, 2880, 1720, 1640, 1460, 1400, 1370, 1200, 1150, 1060, 1020, 990, 880, 820 and 760; ^{1}H-NMR (500 MHz, CDCl$_3$): δ 5.72–5.65 (m, 2H, H6, H7), 3.41–3.27 (m, 2H, $NC\underline{H}$), 2.63–2.54 (m, 1H, H7a), 2.34–2.26 (m, 1H, H3a), 2.20–1.67 (m, 8H, H1, H3, H4, H5), 1.28 (d, 6H, J_{HH} = 6.8 Hz, CH$_3$), 1.28 (6H, d, J_{HH} = 6.8 Hz, CH$_3$); ^{13}C-NMR (125.8 MHz, CDCl$_3$): δ 129.4 (d, $^{3}J_{PC}$ = 9.9 Hz, C7), 127.0 (s, C6), 45.9 (d, $^{2}J_{PC}$ = 4.5 Hz, NC), 37.0 (d, $^{2}J_{PC}$ = 11.1 Hz, C7a), 35.3 (d, $^{2}J_{PC}$ = 9.1 Hz, C3a), 33.7 (d, $^{1}J_{PC}$ = 78.2 Hz, C1), 33.3 (d, $^{1}J_{PC}$ = 79.8 Hz, C3), 25.1 (d, $^{3}J_{PC}$ = 4.9 Hz, C4), 23.3 (s, C5), 23.1 (d, $^{3}J_{PC}$ = 1.7 Hz, NCC), 23.0 (d, $^{3}J_{PC}$ = 1.7 Hz, NCC); ^{31}P-NMR (202.5 MHz, CDCl$_3$): δ −68.2; MS m/z 256 (M$^+$ + 1); HRMS (Fab); Calcd. for $C_{14}H_{27}ONP$: M + 1, 256.1830, Found: M$^+$ + 1, 256.1858.

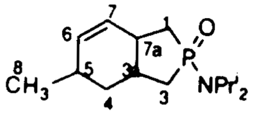
2-(N,N-Diisopopylamino)-2-oxo-5-methyl-3a,4,5,7a-tetrahydro-isophosphindoline **20.** A solution of N,N-diisopropyl-P-(2-propen-1-yl)-P-(2,4-hexadien-1-yl)phosphonamide **18** (0.84 g, 3.12 mmol) in benzene 15 ml in autoclave was heated for 60 hrs at 180–190°C. The reaction mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using AcOEt/EtOH (10:1) as an elute to give **20a** (0.21 g, 25%), **20b** (0.01 g, 1%) and **20c** (0.19 g, 23%), respectively.

20a: IR (neat) ν (cm^{-1}): 2980, 2940, 2880, 1640, 1460, 1400, 1370, 1300, 1210, 1150, 1060, 1020, 990, 880, 820 and 760; ^{1}H-NMR (500 MHz, CDCl$_3$): δ 5.82–5.65 (1H, m, H7), 5.52 (dd, 1H, J_{H6H7} = 9.9 Hz, J_{H5H6} = 1.1 Hz, H6), 3.44–3.19 (m, 2H, $NC\underline{H}$), 2.49–2.27 (m, 2H, H3a, H7a), 2.26–2.10 (m, 1H, H5), 2.10–1.35 (m, 6H, H1, H3, H4), 1.29 (d, 6H, J_{HH} = 6.4 Hz, CH$_3$), 1.28 (d, 6H, J_{HH} = 6.8 Hz, CH$_3$), 0.98 (d, 3H, J_{H5H8} = 7.1 Hz, C8); ^{13}C-NMR (125.8 MHz, CDCl$_3$): δ 133.8 (s, C6), 128.5 (d, $^{3}J_{PC}$ = 14.8 Hz, C7), 45.9 (d, $^{2}J_{PC}$ = 4.6 Hz, NC), 37.3 (d, $^{2}J_{PC}$ = 10.8 Hz, C7a), 35.9 (d, $^{1}J_{PC}$ = 78.8 Hz, C1), 35.3 (d, $^{2}J_{PC}$ = 8.3 Hz, C3a), 34.7 (s, C4), 32.9 (d, $^{1}J_{PC}$ = 77.7 Hz, C3), 31.3 (s, C5), 23.3 (d, $^{3}J_{PC}$ = 1.6 Hz, $NC\underline{C}$), 22.7 (d, $^{3}J_{PC}$ = 1.7 Hz, $NC\underline{C}$), 21.4 (s, C8); ^{31}P-NMR (202.5 MHz, CDCl$_3$): δ −68.9; MS m/z 270 (M$^+$ + 1); HRMS (Fab); Calcd. for $C_{15}H_{29}ONP$: M + 1, 270.1987, Found: M$^+$ + 1, 270.1983.

20b: IR (neat) ν (cm^{-1}): 2980, 2940, 1640, 1450, 1400, 1360, 1300, 1200, 1180, 1140, 1020, 980, 880, 820 and 710; ^{1}H-NMR (500 MHz, CDCl$_3$): δ 5.80–5.49 (m, 2H, H6, H7), 3.45–3.29 (m, 2H, $NC\underline{H}$), 2.50–2.28 (m, 2H, H3a, H7a), 2.09–1.31 (m, 7H, H1, H3, H4, H5), 1.29 (d, 6H, J_{HH} = 6.8 Hz,

CH_3), 1.28 (d, 6H, J_{HH} = 6.7 Hz, CH_3), 1.04 (d, 3H, J_{HH} = 6.7 Hz, C8); ^{13}C-NMR (125.8 MHz, $CDCl_3$): δ 133.8 (d, $^4J_{PC}$ = 1.9 Hz, C6), 128.3 (d, $^3J_{PC}$ = 21.8 Hz, C7), 46.0 (d, $^2J_{PC}$ = 4.3 Hz, NC), 40.3 (d, $^2J_{PC}$ = 11.4 Hz, C7a), 37.1 (d, $^2J_{PC}$ = 7.5 Hz, C3a), 35.9 (d, $^3J_{PC}$ = 16.7 Hz, C4), 35.5 (d, $^1J_{PC}$ = 83.1 Hz, C1), 35.2 (d, $^3J_{PC}$ = 81.7 Hz, C3), 30.0 (d, J_{PC} = 2.3 Hz, C5), 23.4 (d, $^3J_{PC}$ = 2.1 Hz, NC$\underline{C}$), 22.7 (d, $^3J_{PC}$ = 1.8 Hz, NC$\underline{C}$), 22.1 (s, C8); ^{31}P-NMR (202.5 MHz, $CDCl_3$): δ −62.2; MS m/z 270 (M^+ + 1); HRMS (Fab); Calcd. for $C_{15}H_{29}ONP$: M + 1, 270.1987, Found: M^+ + 1, 270.1953.

20c: IR (neat) ν (cm^{-1}): 2980, 2940, 1640, 1450, 1400, 1360, 1300, 1200, 1180, 1140, 1020, 980, 880, 820 and 710; ^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.73 (dddd, 1H, J_{HH} = J_{HH} = 9.7 Hz, $^4J_{PH}$ = 4.5 Hz, $^4J_{HH}$ = 2.7 Hz, H7), 5.53 (m, 1H, H6), 3.47–3.36 (m, 2H, NC$\underline{H}$), 2.84–2.80 (m, 1H, H7a), 2.55–2.39 (m, 1H, H3a), 2.32–1.41 (m, 7H, H1, H3, H4, H5), 1.28 (d, 6H, J_{HH} = 6.8 Hz, NCC$\underline{H}_3$), 1.28 (d, 6H, J_{HH} = 6.7 Hz, NCC$\underline{H}_3$), 0.98 (d, 3H, J_{H5H8} = 7.2 Hz, C8); ^{13}C-NMR (125.8 MHz, $CDCl_3$): δ 133.4 (S, C8), 128.5 (d, $^3J_{PC}$ = 18.6 Hz, C7), 46.3 (d, $^2J_{PC}$ = 4.2 Hz, NC), 36.1 (d, $^3J_{PC}$ = 1.6 Hz, C4), 35.0 (d, $^2J_{PC}$ = 14.6 Hz, C7a), 34.8 (d, $^1J_{PC}$ = 81.3 Hz, C1), 33.7 (d, $^2J_{PC}$ = 7.0 Hz, C3a), 32.8 (d, $^1J_{PC}$ = 79.9 Hz, C3), 30.9 (S, C5), 23.2 (d, $^3J_{PC}$ = 2.2 Hz, NC$\underline{C}$), 22.9 (d, $^3J_{PC}$ = 2.1 Hz, NC$\underline{C}$), 21.6 (s, C8); ^{31}P-NMR (202.5 MHz, $CDCl_3$): δ −66.2; MS m/z 270 (M^+ + 1); HRMS (Fab); Calcd. for $C_{15}H_{29}ONP$: M + 1, 270.1987, Found: M^+ + 1, 270.1953.



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