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Note

The Chemistry of 3-Aminophospholes

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Summary: A 3-morpholinophosphole has been prepared from the appropriate 3-keto-4-phospholene oxide by reaction with morpholine in the presence of $TiCl_4$ as a catalyst, followed by reduction of the phosphoryl group by phenylsilane. Both theoretical and experimental studies show that the amino group enhances the reactivity of the diene but does not affect the lone pair at phosphorus. This observation has been used to devise a generating system for the transient phosphinidene complex [PhP-Fe(CO)$_4$] that has been trapped by alkynes and ethanol.

Introduction

Presently, only a few 2-aminophospholes have been described in the literature, and no chemistry has ever been developed around them.[1] Moreover, 3-aminophospholes are still completely unknown. Since it is well established that phospholes are poorly aromatic,[2] we can expect a strong perturbation of their dienic system by a possible amino substituent. Such a substituent on the β position is expected to sharply increase the basicity of the phosphorus lone pair, which is normally rather low.[3] Hereafter, we attempt to partly fill this lack of data by describing the synthesis and some chemistry of a 3-aminophosphole.

Results and Discussion

In order to have a better insight into the kind of electronic perturbation that can be expected when grafting an amino group on the β position of a phosphole ring, we decided to compare **1** and **2** by DFT computations at the B3LYP/6-311+G(d,p) level.[4]

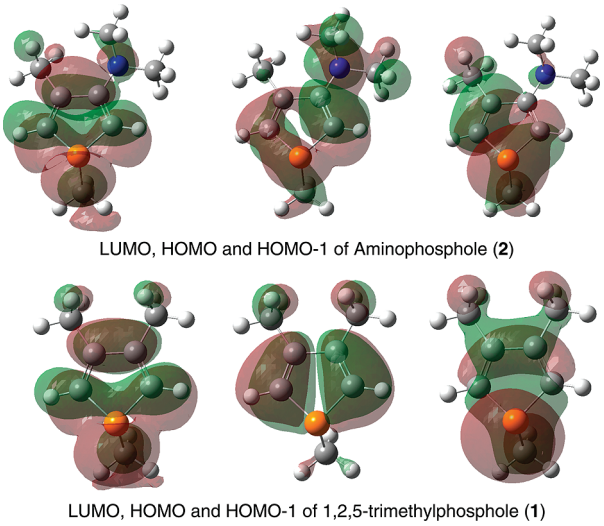
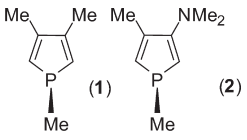


Figure 1. Comparison between the frontier orbitals of phospholes **1** and **2**.



The comparison between the frontier orbitals of **1** and **2** is shown in Figure 1. The LUMO of **2** is shifted to higher energy by 0.13 eV, but its shape is not significantly altered. Whereas the HOMO of **1** is localized on the diene, the HOMO of **2** contains significant contributions from the lone pairs at P and N, and its energy sharply increases by 0.57 eV. Finally, the HOMO−1, which corresponds to the lone pair at P in **1**, is not significantly boosted in energy. As we shall see, these results nicely explain the chemistry of 3-aminophospholes.

The synthesis of our 3-aminophosphole starts from a 3-oxophosphol-4-ene oxide. Some work has been done on such compounds in connection with the synthesis of phosphasugars.[5] These products result from the allylic oxidation

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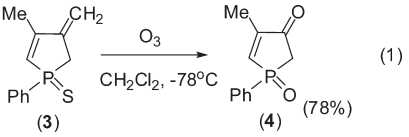
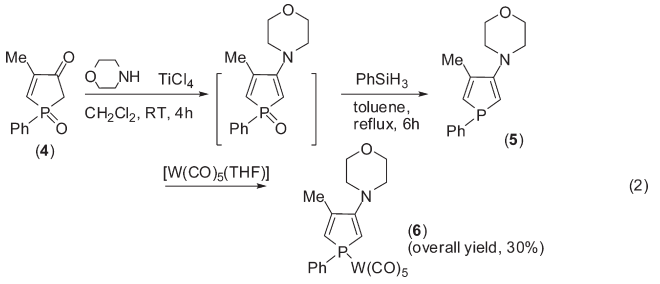
of 2-phospholenes by CrO_3. We have devised a new approach based on the ozone cleavage of the exocyclic C=C double bond of the easily accessible isomeric phosphole sulfide (**3**)[6] (eq 1).



(1)

(**3**) (**4**)

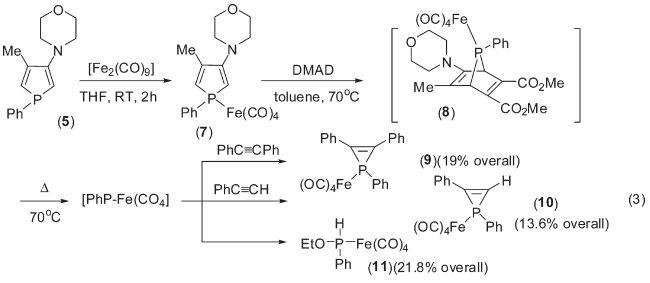
The conversion of **4** into the corresponding 3-aminophosphole **5** is then carried out by reaction with morpholine with $TiCl_4$ as a catalyst, followed by in situ reduction of the phosphoryl group by phenylsilane (eq 2).



(2)

Phosphole **5** displays two vinylic protons at 6.59 ($^2J_{HP}$ = 35 Hz) and 5.75 ppm ($^2J_{HP}$ = 30 Hz). The ^{13}C spectrum shows a β =C(N) at 160.77 and the corresponding α =CH at 109.09 ppm with no detectable C−P coupling. Due to its high sensitivity toward hydrolysis and oxidation, phosphole **5** was more fully characterized as its P−$W(CO)_5$ complex **6**. The $^1J_{PW}$ coupling of 219 Hz is especially noteworthy. It can be compared with the similar coupling in the 1-phenyl-3,4-dimethylphosphole P−$W(CO)_5$ complex (214.7 Hz). Since this value is correlated with the basicity of the P lone pair,[7] it seems to indicate that the amino substitution does not significantly alter the basicity of P, contrary to what we expected. It must be recalled that the lone pair orbital of **2** is almost at the same level of energy as that of the corresponding orbital of **1**. Since we know that the electronic delocalization is weak within the phosphole ring, this might explain this observation.

Our theoretical results suggest that the main change in the chemistry of **2** versus **1** is the boosted reactivity of the dienic system. The main use of the dienic reactivity of phospholes is the synthesis of the 7-phosphanorbornadiene precursors of terminal phosphinidene complexes.[8] This scheme is characterized by the wide range of possible substituents at phosphorus but is limited to a few complexing groups, in practice only Cr, Mo, and $W(CO)_5$. We decided to check whether it was possible to use a phosphole such as **5** to build a precursor of [PhP-Fe$(CO)_4$]. Lammertsma has already studied the generation and trapping of [^{i}Pr$_2$N-P-Fe$(CO)_4$] from Na_2Fe$(CO)_4$.[9] Although quite simple, his approach is restricted to the amino substituent. The reaction of **5** with $Fe_2(CO)_9$ affords the [Fe$(CO)_4$] complex **7**. Upon complexation, the ^{31}P resonance of **5** is shifted from −7 to +61 ppm. Since the reaction is clean and quantitative, the complex was used without further purification. It readily reacts with dimethyl acetylenedicarboxylate at 70 °C, but it appears that the resulting 7-phosphanorbornadiene complex **8** is unstable even under these mild conditions. Thus we followed the same approach as for the study of the generation and trapping of [ClP-$W(CO)_5$].[10] The reaction with DMAD was performed in the presence of the trapping reagents. In so doing, we were able to obtain the phosphirene complexes **9** and **10** from the appropriate alkynes and the secondary phosphinite complex from ethanol (eq 3). It must be stressed that the same scheme does not work when applied to 1-phenyl-3,4-dimethylphosphole, thus highlighting the higher reactivity of **5**. In line with the findings of Lammertsma, we were unable to obtain the phosphirane complexes when using the alkenes as trapping reagents.



(3)

The modest yields probably reflect the modest stability of the products. A generalization of this approach to other complexing groups appears possible.

Experimental Section

NMR spectra were obtained on a JEOL ECA400 or JEOL ECA400SL spectrometer. All spectra were recorded at 298 K unless otherwise specified. HRMS spectra were obtained in ESI mode on a Finnigan MAT95XP HRMS system (Thermo Electron Corp.). All reactions were performed under argon. Silica gel (230−400 mesh) was used for the chromatographic separations. All commercially available reagents were used as received from the suppliers. Most of the products show a high sensitivity toward moisture, and their elemental analyses have been replaced by exact mass measurements.

Isomeric Phosphole Sulfide 3. To a solution of 1-phenyl-3,4-dimethylphosphole sulfide (2.0 g, 9.1 mmol) in 30 mL of THF at −78 °C and under argon was added sodium bis(trimethylsilyl)amide (5 mL of a 2 M solution in THF) via a syringe. After stirring for about 10 min, 4 mL of 3 N HCl was added via a syringe; the mixture was stirred for another 10 min at −78 °C, then slowly warmed to room temperature. After extraction, the organic layer was dried with $MgSO_4$. The residue was chromatographed with CH_2Cl_2−hexane (70:30) to give **3**. Yield: 1.4 mg, 70%. ^{31}P NMR (162 MHz, $CDCl_3$): δ 49.2. ^1H NMR (400 MHz, $CDCl_3$): δ 2.10 (s, 3H, CH_3), 3.11−3.21 (m, 2H, P-CH_2), 5.24 (d, J = 1.84 Hz, 1H, =CH_2), 5.40 (s, 1H, =CH_2), 6.06 (d, J = 25.64 Hz, 1H, P-CH), 7.40−7.47 (m, 3H, Ph), 7.75−7.81 (m, 2H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 16.53 (d, J = 17.2 Hz, CH_3), 40.36 (d, J = 60.35 Hz, P-CH_2), 113.04 (d, J = 13.42 Hz, =CH_2), 127.52 (d, J = 78.55 Hz, P-CH), 128.61 (d, J = 12.46, Ph),

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130.93 (d, J = 11.49 Hz, Ph), 131.76 (d, J = 28.7 Hz, Ph), 132.81 (d, J = 79.52, Ph), 145.48 (d, J = 9.58 Hz), 156.70 (d, J = 12.46 Hz).

4-Ketophospholene (4). A 2.0 g (9.1 mmol) amount of **3** was dissolved in 50 mL of CH_2Cl_2. A stream of ozone was bubbled through the solution at −78 °C. Ozone treatment was terminated when the mixture turned blue. A stream of O_2 removed the excess ozone; then an excess of dimethyl sulfide was added. The mixture was slowly warmed to room temperature and stirred overnight. After removal of the solvent, the product was purified by column chromatography with CH_2Cl_2−EtOH (40:1). Yield: 1.46 mg, 78%. ^{31}P NMR (162 MHz, $CDCl_3$): δ 31.12. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.08 (s, 3H, CH_3), 2.79−2.99 (m, 2H, CH_2), 7.22 (d, J = 16.48 Hz, 1H, P-CH), 7.48−7.56 (m, 5H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.82 (d, J = 16.11 Hz, CH_3), 37.78 (d, J = 73.64 Hz, P-CH_2), 129.21 (d, J = 12.65 Hz, Ph), 130.76 (d, J = 10.36 Hz, Ph), 132.84 (d, J = 2.3 Hz, Ph), 143.42 (d, J = 82.84 Hz, P-CH), 158.03 (d, J = 5.75 Hz), 197.12 (d, J = 19.56, C═O).

3-Aminophosphole (5). A 0.2 g (0.97 mmol) amount of **4** was dissolved in 10 mL of CH_2Cl_2, followed by 1 mL (excess) of morpholine. Then 0.4 mL of $TiCl_4$ (1 M in toluene) was added slowly at 0 °C. The mixture was slowly warmed to room temperature, stirred for 4 h, and then filtered. The solvent was evaporated, and the residue was dissolved in 10 mL of toluene. $PhSiH_3$ (0.2 mL, excess) was added to the solution, which was refluxed for 6 h. The solvent was evaporated, and phosphole **5** was extracted with hexane. ^{31}P NMR (162 MHz, $CDCl_3$): δ −7.6. ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.16 (dd, J = 1.4 and 2.7 Hz, 3H, CH_3), 2.85−3.04 (dm, 4H, NCH_2), 3.78−3.84 (m, 4H, OCH_2), 5.75 (dd, J = 2.7, 30 Hz, 1H, P-CH), 6.59 (dm, J = 35.26 Hz, 1H, P-CH), 7.23−7.47 (m, 5H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 17.45 (s, CH_3), 51.75 (s, NCH2), 67.02 (s, OCH_2), 109.09 (s, P-CH═), 145.77 (s, Me-C═), 160.76 (d, J = 10.5 Hz, ═C-N).

3-Aminophosphole Tungsten Complex 6. Phosphole **5** was made from 0.2 g of starting material **4** as described before. Then 0.5 mmol of [$W(CO)_5$(THF)] in 10 mL of THF was added to the phosphole **5**, and the mixture was stirred overnight at room temperature. Complex **6** was recrystallized from CH_2Cl_2. Yield: 169.6 mg, 30% overall. ^{31}P NMR (162 MHz, CD_2Cl_2): δ 4.73 (J_{P-W} = 219.1 Hz). ^{1}H NMR (400 MHz, CD_2Cl_2): δ 2.21 (s, 3H, CH_3), 2.93−3.04 (dm, 4H, NCH_2), 3.77−3.79 (m, 4H, OCH_2), 5.67 (d, J = 32.28 Hz, 1H, P-CH), 6.63 (d, J = 33.44 Hz, 1H, P-CH), 7.37−7.38 (m, 3H, Ph), 7.49−7.54 (m, 2H, Ph). ^{13}C NMR (100 MHz, CD_2Cl_2): δ 17.06 (d, J = 11.5 Hz, CH_3), 51.40 (d, J = 2.87 Hz, NCH_2), 66.48 (d, J = 1.92 Hz, OCH_2), 107.1 (d, J = 49.8 Hz, P-CH═), 128.74 (d, J = 10.54 Hz, Ph), 130.3 (s, Ph), 131.11 (d, J = 12,46 Hz, Ph), 132.17 (d, J = 40.29 Hz, P-C(Ph)), 133.21 (d, J = 41.68 Hz, P-CH═), 147.78 (d, J = 5.75 Hz, C-Me), 161.05 (d, J = 15.33 Hz, N-C), 199.56 (d, J = 18.2 Hz, *trans* C═O), 196.59 (d, J = 6.71 Hz, *cis* C═O). Most of the resonances are double due to the presence of two almost undistinguishable diastereomers. Exact mass: calcd for $C_{20}H_{18}NO_6P^{183}W$, 582.0374; found, 582.0372.

Triphenylphosphirene Iron Complex 9. Phosphole **5** was obtained from 0.2 g of starting material **4**. The phosphole was dissolved in 10 mL of THF, $Fe_2(CO)_9$ (0.3 g, 0.82 mmol) was added, the mixture was stirred for 2 h at room temperature and monitored by ^{31}P, and the peak at −7 shifted to 61 ppm. The solvent was removed under vacuum, the residue was dissolved in 10 mL of toluene, and an excess of dimethyl acetylenedicarboxylate and diphenylacetylene were added. The reaction mixture was then heated under argon at 70 °C overnight. After removal of the solvent, the product was purified by chromatography with hexane−CH_2Cl_2 (40:3). Yield: 83 mg, 18.9% (overall). ^{31}P NMR (162 MHz, $CDCl_3$): δ −90.3. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33−7.88 (m, 15H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 127.02 (d, J = 5.73 Hz, Ph), 128.42 (d, J = 8.59 Hz, Ph), 129.55 (s, Ph), 128.77 (d, J = 11.45 Hz), 130.47 (d, J = 5.72 Hz, Ph), 130.62 (d, J = 6.68 Hz, Ph), 131.07 (s, Ph), 131.71 (s, Ph), 132 (d, J = 14.31 Hz), 135.98 (d, J = 17.18 Hz, P-C(Ph)), 213.22 (d, J = 22.9, C═O). Exact mass: calcd for $C_{24}H_{16}O_4PFe$, 455.0136; found, 455.0145.

1,2-Diphenylphosphirene Iron Complex 10. The same experiment as for **9** was used, with phenylacetylene instead of diphenylacetylene. The product was purified by chromatography with hexane−CH_2Cl_2 (35:5). Yield: 50 mg, 13.6% (overall). ^{31}P NMR (162 MHz, $CDCl_3$): δ −85.5. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.50 (d, J = 19.68, 1H, ═CH−), 7.39−7.72 (m, 10H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 120.20 (d, J = 4.77 Hz, P-CH═), δ 125.65 (d, J = 6.68 Hz, Ph), 128.62 (d, J = 11.45 Hz), 129.43 (s, Ph), 130.43 (d, J = 4.77, Ph), 131.13 (s, Ph), 131.81 (d, J = 6.67 Hz, Ph), 131.99 (s, Ph), 136.94 (d, J = 18.3 Hz, P-C(Ph)), 141.84 (d, J = 9.54 Hz), 213.15 (d, J = 22.9 Hz, C═O). Exact mass: calcd for $C_{18}H_{12}O_4PFe$, 378.9823; found, 378.9821.

Secondary Phosphinite Iron Complex 11. The same experiment as for **9** was used, with EtOH instead of diphenylacetylene. The product was purified by chromatography with hexane−CH_2Cl_2 (35:5). Yield: 70 mg, 21.8% (overall). ^{31}P NMR (162 MHz, $CDCl_3$): δ 153.34. ^{31}P{^{1}H} NMR: δ 153.36 (d, J_{P-H} = 390). ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.30 (t, J = 6.88 Hz, 3H, CH_3), 3.84 (q, J = 8.72 Hz, 2H, CH_2), 7.92 (d, J_{P-H} = 391.4, 1H, P-H), 7.54 (s, 3H, Ph), 7.70−7.75 (m, 2H, Ph). ^{13}C NMR (100 MHz, $CDCl_3$): δ 16.12 (d, J = 7.66 Hz, CH_3), 67.14 (d, J = 11.5 Hz, CH_2), 129.14 (d, J = 10.54 Hz, Ph), 130.42 (d, J = 10.54 Hz, Ph), 132.19 (d, J = 1.91 Hz, Ph), 134.33 (d, J = 52.69 Hz, P-C(Ph)), 212.37 (d, J = 22.04 Hz, C═O). Exact mass: calcd for $C_{12}H_{12}O_5PFe$, 322.9772; found, 322.9778.

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