# Totally Regio- and Stereoselective P–O-to-P–C Rearrangement in the Synthesis of Chiral *P*-(*o*-Hydroxyaryl)diazaphospholidine *P*-Oxides

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The totally regio- and stereoselective P–O-to-P–C rearrangement in the synthesis of various chiral *P*-(*o*-hydroxyaryl)diaza-phospholidine *P*-oxides has been investigated. This reaction proceeds with excellent yields ranging from 72 to 92%, total retention of configuration at the phosphorus atom, and complete regioselectivity. An exception was found with naphthyl derivatives, which gave mixtures of two regioisomers. In all cases, the products generated have been unambiguously characterized by $^{1}$H-, $^{13}$C-, and $^{31}$P-NMR spectroscopy as well as by X-ray-diffraction analysis.

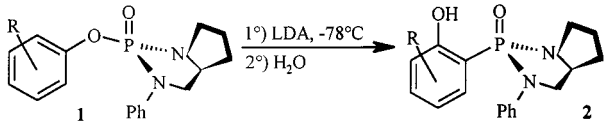
## Introduction

We have recently reported a new general procedure for the preparation of various chiral *P*-(*o*-hydroxyaryl)diaza-phospholidine *P*-oxides, *P*-(*o*-hydroxyaryl)oxazaphospholidine *P*-oxides, and *P*-(*o*-hydroxyaryl)phosphonates.[1] This method, which relies on the properties of a Phosphoryl-Directed Metallation Group (P-DMG), involves a stereoselective P−O-to-P−C rearrangement[2−5] with a total retention of configuration at the phosphorus atom. These compounds,[6] which feature a basic (P=O) and an acid (OH) site, have found application as catalysts in the asymmetric addition of diethylzinc to aromatic aldehydes, offering enantiomeric excesses of up to 95%.[7]

In the realm of heteroatom-containing Directed Metallation Groups (DMGs), existing phosphorus-based DMGs have limitations owing to synthetic inaccessibility, ineffective directing ability, and competing side reactions.[8] Although the directed *ortho*-metallation-induced 1,3-migration reaction is now well known using tertiary amide and *O*-carbamate directors in the regiospecific preparation of polysubstituted aromatic compounds,[9] no studies have been reported using the phosphanyl directing group. In this paper, we report that total regioselectivity can be achieved in this reaction by varying the nature and the position of the substituents on the phenoxy group of the chiral diaza-phospholidine *P*-oxide precursors.

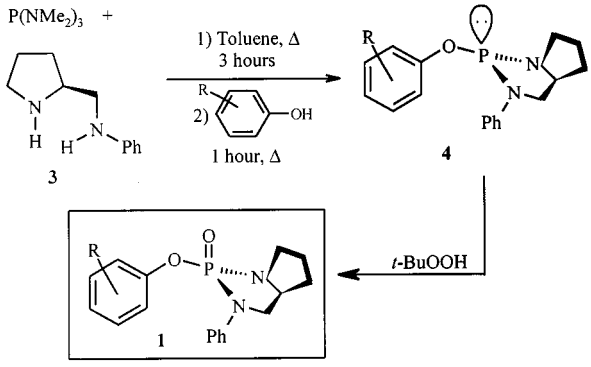
## Results and Discussion

Chiral *P*-(*o*-hydroxyaryl)diazaphospholidine *P*-oxides **2** may be synthesized from precursors **1** in a two-step sequence involving an unstable metallated intermediate. The latter undergoes a fast 1,3-rearrangement with formation of a phosphorus−carbon bond[10] (Scheme 1).




Scheme 1. General procedure for the synthesis of *P*-(*o*-hydroxyaryl)diazaphospholidine *P*-oxides **2**

Precursors **1** could easily be obtained by carrying out an exchange reaction between tris(dimethylamino)phosphane and (*S*)-(+)-2-(anilinomethyl)pyrrolidine (**3**) for 2 h at 110°C in toluene, followed by addition of the appropriate phenol. Oxidation of the crude phosphanes **4** with *tert*-butyl hydroperoxide afforded the expected compounds **1** with chemical yields ranging from 63 to 84% (Scheme 2). Moreover, in almost all cases only one diastereomer was obtained, which was characterized as the thermodynamic *anti* diastereomer[13] (Table 1).




Scheme 2. General procedure for the synthesis of precursors **1**

A subsequent P−O-to-P−C rearrangement upon treatment of precursors **1** with LDA in THF at −78°C resulted in the stereoselective formation of the corresponding *P*-(*o*-hydroxyaryl)diazaphospholidine *P*-oxides **2**. In all cases, this reaction was found to proceed with total retention of

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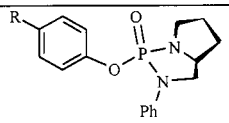
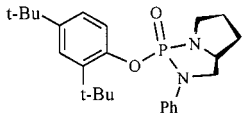
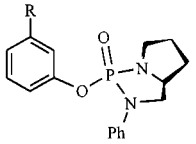
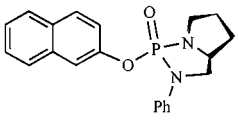
Table 1. Synthesis of precursors **1**

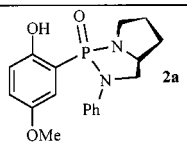
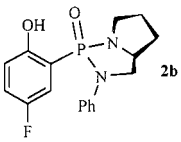
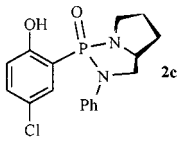
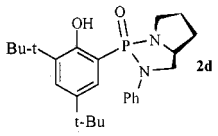
| Entry | Product | | Diastereomeric ratio (%) [a] | Yield (%) [b] |
|---|---|---|---|---|
| 1 |  | R = OMe | **1a** 95 / 5[c] | 84 |
| | | F | **1b** 95 / 5[c] | 83 |
| | | Cl | **1c** 100 / 0 | 81 |
| 2 |  | | **1d** 100 / 0 | 63 |
| 3 |  | R = OMe | **1e** 100 / 0 | 75 |
| | | F | **1f** 100 / 0 | 75 |
| | | Cl | **1g** 100 / 0 | 70 |
| | | *t*-Bu | **1h** 100 / 0 | 63 |
| 4 |  | | **1i** 94 / 6[c] | 77 |

[a] Diastereomeric ratio determined by $^{31}$P-NMR spectroscopy. – [b] Isolated yield after column chromatography. – [c] Inseparable mixture of diastereomers.

configuration at the phosphorus atom[14] and with complete regioselectivity.[16]

Reactions of *para*-substituted precursors **1a**–**d** led exclusively to the expected products in chemical yields of 76–82% by 1,3-migration of the phosphanyl group from the oxygen to the adjacent carbon atom in the *ortho* position (Table 2).

Table 2. Stereoselective P–O-to-P–C rearrangement of precursors **1a**–**1d**

| Entry | Precursor 1 | Product | Regioselectivity (%)[a] | Yield (%)[b] |
|---|---|---|---|---|
| 1 | **1a** |  **2a** | 100 | 86[c] |
| 2 | **1b** |  **2b** | 100 | 76[c] |
| 3 | **1c** |  **2c** | 100 | 77[c] |
| 4 | **1d** |  **2d** | 100 | 76[c] |

[a] Regioselectivity determined by $^{31}$P-NMR spectroscopy. – [b] Isolated yield after column chromatography. – [c] Total diastereoselectivity was observed by $^{31}$P-NMR analysis.

The structures of the final products obtained were determined by $^{1}$H- and $^{13}$C-NMR-spectroscopic analysis and verified for compound **2b** by X-ray diffraction analysis (Figure 1).[17]

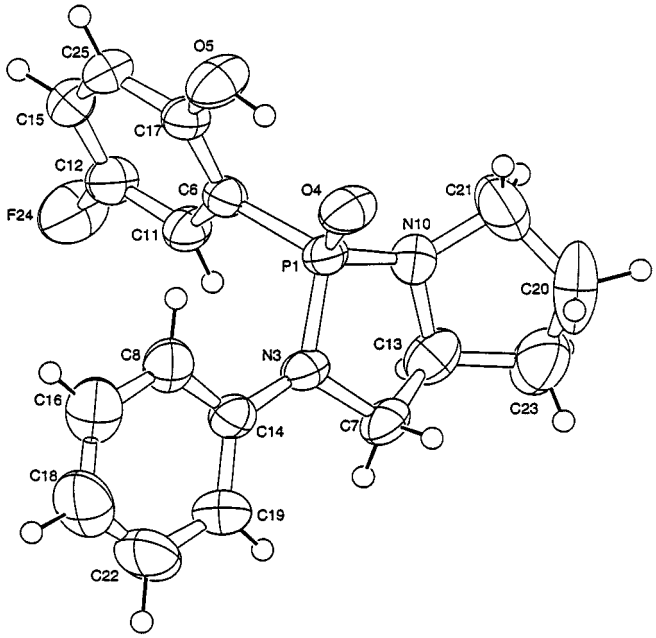


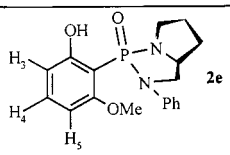
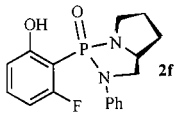
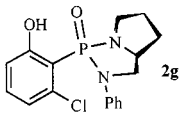
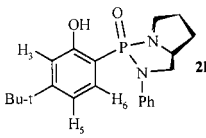
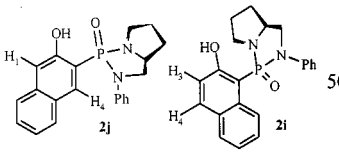

Figure 1. Structure of **2b**, showing labeling scheme; selected bond lengths [Å]: P1–O4 1.484(2), P1–N3 1.662(2), P1–N10 1.631(2), P1–C6 1.794(2), O5–C17 1.351(2), C14–N3 1.417(2), C12–F24 1.368(3); selected bond angles [°]: O4–P1–N10 115.7(1), O4–P1–N3 118.2(1), O4–P1–C6 107.6(1), N3–P1–N10 94.7(1), N3–P1–C6 109.1(1), N10–P1–C6 111.0(1), P1–N3–C14 125.4(2), P1–N3–C7 111.8(1), C14–N3–C7 121.3(2), P1–N10–C21 124.5(2), P1–N10–C13 113.1(2)

In the case of **2b**, the configuration at the phosphorus atom is seen to be retained during the rearrangement. The sum of the bond angles around the nitrogen atom of the pyrrolidine ring is 347.8°, indicating a non-planar configuration. The phenyl ring (C14–C19) is almost coplanar with the atoms N3, P1, C7, and the bond length C14–N3 is short (1.417 Å). These observations are suggestive of an interaction between the lone pair of the nitrogen atom and the aromatic system. Moreover, there is evidently a strong hydrogen bond between the hydroxy group and the oxygen atom attached to the phosphorus moiety.

On the other hand, P–O-to-P–C rearrangement of *meta* precursors **1e**–**h** led to the corresponding *P*-(*o*-hydroxyaryl)diazaphospholidine *P*-oxides in high chemical yields ranging from 72 to 92% (Table 3).

In each case, only one regioisomer was obtained, which was isolated and fully characterized by NMR-spectroscopic analysis of the coupling constants shown by the aromatic protons of the phenol moiety. Thus, the $^{1}$H-NMR spectrum of **2e** featured two doublets of doublets attributable to 3-H and 5-H, respectively. Similar analyses of compounds **2f** and **2g** led to the same conclusion concerning the regioselectivity of this reaction. Moreover, an X-ray diffraction analysis of **2f** was carried out, which confirmed beyond any doubt the validity of the proposed structure (Figure 2).[18]

Table 3. Stereoselective P−O-to-P−C rearrangement of precursors **1e−1i**

| Entry | Precursor 1 | Product | Regioselectivity (%)[a] | Yield (%)[b] |
|---|---|---|---|---|
| 1 | **1e** |  **2e** | 100 | 72[c] |
| 2 | **1f** |  **2f** | 100 | 85[c] |
| 3 | **1g** |  **2g** | 100 | 92[c] |
| 4 | **1h** |  **2h** | 100 | 84[c] |
| 5 | **1i** |  **2j** **2i** | 50 | 78[c] |

[a] Regioselectivity determined by $^{31}$P-NMR spectroscopy. − [b] Isolated yield after column chromatography. − [c] Total diastereoselectivity was observed by $^{31}$P-NMR analysis.

Thus, in these three cases, conjugation of the *ortho*-orienting character of the MeO, F, and Cl groups with the *ortho*-orienting phosphoryl group led to the exclusive formation of a single regioisomer.

Due to the significant steric hindrance of the *tert*-butyl group, rearrangement of precursor **1h** proceeded with complete regioselectivity at C-1. In this case, the $^1$H-NMR spectrum featured two doublets of doublets attributable to 3-H and 6-H and a doublet of doublets of doublets attributable to 5-H.

The crude product obtained by reaction of precursor **1i** with 2 equiv. of LDA showed two signals in its $^{31}$P-NMR spectrum at δ = 32.3 and δ = 34.3, in a 75:25 intensity ratio. The major product was isolated and characterized as *P*-(3-hydroxy-2-naphthyl)diazaphospholidine *P*-oxide **2j**. In its $^1$H-NMR spectrum, doublets were seen at δ = 7.81 with $^3J_{P-H}$ = 17.8 Hz and at δ = 7.31 with $^4J_{P-H}$ = 6.2 Hz, attributable to 4-H and 1-H (numbering refers to Table 3), respectively.

Isolation of the minor product and subsequent $^1$H-NMR analysis confirmed the proposed structure **2i**. Thus, in this case, lithiation of **1i** probably occurs at both the 1 and 3 positions, resulting in 1,3-P−O-to-P−C migration to either of the metallated positions, leading to a mixture of two products.[19]

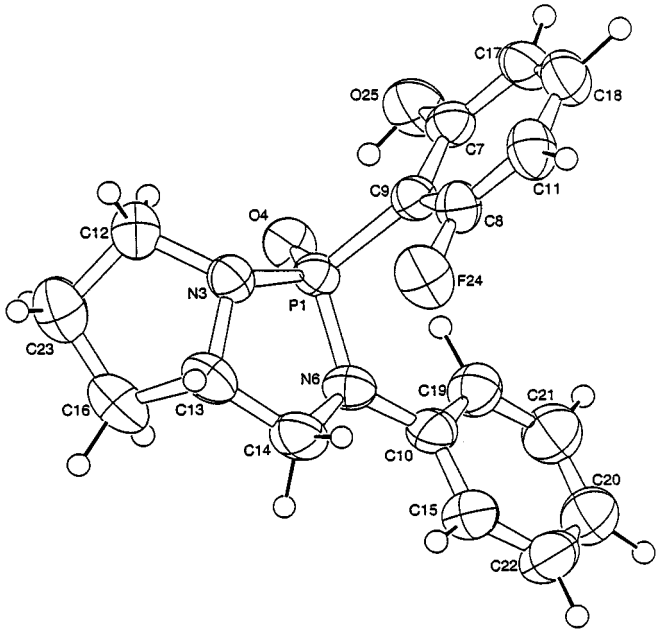



Figure 2. Structure of **2f**, showing labeling scheme; selected bond lengths [Å]: P1−O4 1.481(1), P1−C9 1.796(1), P1−N3 1.647(1), P1−N6 1.654(1), O25−C7 1.338(2), C8−F24 1.364(2), N6−C10 1.415(2); selected bond angles [°]: O4−P1−N3 116.6(1), O4−P1−N6 116.4(1), O4−P1−C9 106.4(1), N3−P1−N6 96.1(1), N3−P1−C9 111.4(1), N6−P1−C9 109.7(1), P1−N3−C12 120.5(1), P1−N3−C13 111.1(1), C14−N6−C10 120.1(1), P1−N6−C10 125.7(1), P1−N6−C14 112.8(1)

## Conclusion

We have described the synthesis of some new chiral *P*-(*o*-hydroxyaryl)diazaphospholidine *P*-oxides using a stereoselective rearrangement procedure that proceeds with complete regioselectivity. Further studies concerning the use of such compounds as chiral synthons or as catalysts in various asymmetric catalyzed reactions are currently in progress.

## Experimental Section

**General:** $^1$H-, $^{13}$C-, $^{31}$P-, and $^{19}$F-NMR spectra: Bruker AC100, AC200, or AC400 spectrometers in $CDCl_3$ solution. Chemical shifts (δ values) are referenced to $Me_4Si$ ($^1$H and $^{13}$C) and 85% $H_3PO_4$ ($^{31}$P). − Toluene and tetrahydrofuran (THF) were distilled from sodium/benzophenone ketyl immediately prior to use. Ethyl acetate and petroleum ether (boiling range 35−60°C) were purchased from SDS and used without any prior purification. − Column chromatography was performed on SDS silica gel (70−230 mesh). − LDA (2 M in THF) and *tert*-butyl hydroperoxide (5.5 M in decane) were purchased from Fluka. (*S*)-2-(Anilinomethyl)pyrrolidine (**3**) was prepared according to a literature procedure.[20]

**General Procedure for the Preparation of Compounds 1a−i:** A two-necked, round-bottomed flask was charged with tris(dimethylamino)phosphane (5 mmol, 0.82 g) and (*S*)-(+)-2-(anilinomethyl)pyrrolidine (**3**, 5 mmol, 0.88 g) in dry toluene (10 mL) under argon and the mixture was heated at 110°C for 3 h. Then, one equivalent of the appropriate phenol was added at room temperature and the mixture was heated at 110°C for a further 1 h. After cooling to room temperature, the toluene was removed in vacuo. The crude

phosphane was taken up in dichloromethane (15 mL) and this solution was cooled to 0°C. Then, *tert*-butyl hydroperoxide 0.9 mL (5.5 M in decane) was slowly added and the resulting mixture was stirred for 3 h. After removal of the solvent in vacuo, the crude product was purified by chromatography or by crystallization.

**(2*S*,5*S*)-2-(4-Methoxyphenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1a):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 75:25) afforded **1a** as a white solid in 84% yield (the product was obtained as a 95:5 mixture of two diastereomers). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.62 (m, 1 H), 1.88 (m, 3 H), 3.06 (m, 3 H), 3.30 (m, 3 H), 3.38 (m, 2 H), 3.71 (s, 3 H), 3.82 (m, 1 H), 6.71 (dd, *J* = 6.8 Hz, *J* = 2.4 Hz, 2 H), 6.90 (m, 3 H), 7.26 (m, 4 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, *J* = 4.1 Hz), 32.4 (d, *J* = 2.7 Hz), 46.6 (d, *J* = 2.7 Hz), 49.8 (d, *J* = 17.4 Hz), 55.6, 57.0 (d, *J* = 9.7 Hz), 114.4 (s, 2 C), 116.2 (d, *J* = 4.4 Hz, 2 C), 121.4, 122.0 (d, *J* = 4.3 Hz, 2 C), 129.4 (s, 2 C), 141.3 (d, *J* = 5.8 Hz), 144.6 (d, *J* = 10.1 Hz), 156.5. − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 17.0 (major) and 11.0 (minor). − $C_{18}H_{21}N_2O_3P$ (344.3): calcd. C 62.8, H 6.1, N 8.1, P 9.0; found C 62.7, H 6.2, N 8.1, P 9.1.

**(2*S*,5*S*)-2-(4-Fluorophenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1b):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 75:25) afforded **1b** as a white solid in 83% yield (the product was obtained as a 95:5 mixture of two diastereomers). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.67 (m, 1 H), 1.93 (m, 3 H), 3.11 (m, 1 H), 3.29 (m, 1 H), 3.44 (m, 2 H), 3.83 (m, 1 H), 6.89 (m, 5 H), 7.25 (m, 4 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.0 (d, *J* = 3.7 Hz), 32.3 (d, *J* = 2.3 Hz), 46.5, 49.6 (d, *J* = 17.6 Hz), 57.0 (d, *J* = 10.1 Hz), 115.8 (d, *J* = 19.5 Hz, 2 C), 116.1 (s, 2 C), 121.6, 122.4 (dd, *J* = 7.7 Hz, *J* = 3.6 Hz, 2 C), 129.3 (s, 2 C), 141.0 (d, *J* = 5.7 Hz), 146.9 (d, *J* = 8.9 Hz), 159.5 (d, *J* = 240.9 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 17.0 (major) and 11.2 (minor). − $^{19}$F NMR (94.2 MHz, $CDCl_3$): δ = −73.9. − $C_{17}H_{18}FN_2O_2P$ (332.3): calcd. C 61.4, H 5.5, N 8.4, P 9.3; found C 61.4, H 5.4, N 8.3, P 9.4.

**(2*S*,5*S*)-2-(4-Chlorophenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo-[3.3.0]octan-2-one (1c):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1c** as a white solid in 81% yield; m.p. 104°C. − $[\alpha]_D^{20}$ = −103 (*c* = 0.59, $CH_2Cl_2$). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.67 (m, 1 H), 2.02 (m, 3 H), 3.10 (m, 1 H), 3.33 (m, 1 H), 3.48 (m, 2 H), 3.84 (m, 1 H), 6.95 (m, 3 H), 7.26 (m, 6 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, *J* = 4.0 Hz), 32.4 (d, *J* = 2.6 Hz), 46.7 (d, *J* = 2.6 Hz), 49.7 (d, *J* = 17.7 Hz), 57.1 (d, *J* = 10.2 Hz), 116.3 (d, *J* = 5.3 Hz, 2 C), 121.8 (s, 2 C), 122.2, 122.6 (d, *J* = 4.2 Hz, 2 C), 129.5 (s, 2 C), 130.2, 141.1, 149.8 (d, *J* = 8.6 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.6. − $C_{17}H_{18}ClN_2O_2P$ (348.8): calcd. C 58.5, H 5.2, N 8.0, P 8.9; found C 58.5, H 5.3, N 7.9, P 8.9.

**(2*S*,5*S*)-2-(2,4-Di-*tert*-butylphenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1d):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1d** as a white solid in 63% yield; m.p. 150°C. − $[\alpha]_D^{20}$ = −59 (*c* = 0.26, $CH_2Cl_2$). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.29 (s, 18 H), 1.91 (m, 4 H), 3.04 (m, 1 H), 3.44 (m, 1 H), 3.83 (m, 3 H), 6.99 (m, 1 H), 7.13 (dd, *J* = 8.5 Hz, *J* = 2.4 Hz, 1 H), 7.30 (m, 6 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.0, 30.1 (s, 3 C), 31.6 (s, 3 C), 32.6, 34.5, 34.9, 47.4, 49.7 (d, *J* = 18.7 Hz), 57.2 (d, *J* = 10.0 Hz), 116.7 (d, *J* = 3.3 Hz, 2 C), 118.4 (d, *J* = 2.7 Hz), 121.8, 123.8, 124.3, 129.3 (s, 2 C), 138.8 (d, *J* = 8.4 Hz), 141.2 (d, *J* = 5.6 Hz), 146.0, 148.6 (d, *J* = 5.3 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 15.9. − $C_{25}H_{35}N_2O_2P$ (426.5): calcd. C 70.4, H 8.3, N 6.6, P 7.3; found C 70.3, H 8.2, N 6.7, P 7.1.

**(2*S*,5*S*)-2-(3-Methoxyphenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1e):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1e** as a pale yellow solid in 75% yield; m.p. 102°C. − $[\alpha]_D^{20}$ = −83 (*c* = 1.1, $CH_2Cl_2$). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.66 (m, 1 H), 1.95 (m, 3 H), 3.08 (m, 1 H), 3.32 (m, 1 H), 3.45 (m, 1 H), 3.59 (m, 1 H), 3.62 (s, 3 H), 3.82 (m, 1 H), 6.52 (dd, *J* = 3.8 Hz, *J* = 2.6 Hz, 1 H), 6.65 (m, 2 H), 6.99 (t, *J* = 7.1 Hz, 1 H), 7.18 (m, 5 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, *J* = 4.1 Hz), 32.4 (d, *J* = 2.7 Hz), 46.6, 49.6 (d, *J* = 18.4 Hz), 55.2, 57.1 (d, *J* = 10.2 Hz), 107.0 (d, *J* = 5.1 Hz), 110.9, 113.2 (d, *J* = 4.0 Hz), 116.2 (d, *J* = 5.3 Hz, 2 C), 121.6, 129.3 (s, 2 C), 129.8, 141.2 (d, *J* = 5.6 Hz), 152.0 (d, *J* = 9.2 Hz), 160.4. − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.4. − $C_{18}H_{21}N_2O_3P$ (344.3): calcd. C 62.8, H 6.1, N 8.1, P 9.0; found C 62.6, H 6.2, N 8.2, P 9.0.

**(2*S*,5*S*)-2-(3-Fluorophenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1f):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1f** as a pale yellow solid in 75% yield; m.p. 135°C. − $[\alpha]_D^{20}$ = −110 (*c* = 0.60, $CH_2Cl_2$). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.70 (m, 1 H), 1.99 (m, 3 H), 3.10 (m, 1 H), 3.33 (m, 1 H), 3.55 (m, 2 H), 3.85 (m, 1 H), 6.81 (m, 3 H), 7.00 (t, *J* = 7.2 Hz, 1 H), 7.24 (m, 5 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, *J* = 3.0 Hz), 32.4 (d, *J* = 2.7 Hz), 46.7 (d, *J* = 2.7 Hz), 49.7 (d, *J* = 18.7 Hz), 57.1 (d, *J* = 10.1 Hz), 109.0 (dd, *J* = 23.9 Hz, *J* = 4.8 Hz), 111.8 (d, *J* = 21.7 Hz), 116.3 (d, *J* = 4.4 Hz, 2 C), 121.8, 126.9 (t ≡ dd, *J* = 3.6 Hz), 129.4 (s, 2 C), 130.2 (d, *J* = 9.9 Hz), 141.0 (d, *J* = 5.8 Hz), 152.2, 162.9 (d, *J* = 245.6 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.6. − $^{19}$F NMR (94.2 MHz, $CDCl_3$): δ = −81.0. − $C_{17}H_{18}FN_2O_2P$ (332.3): calcd. C 61.4, H 5.5, N 8.4, P 9.3; found C 61.3, H 5.7, N 8.3, P 9.1.

**(2*S*,5*S*)-2-(3-Chlorophenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1g):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1g** as a white solid in 70% yield; m.p. 93°C. − $[\alpha]_D^{20}$ = −96 (*c* = 0.45, $CH_2Cl_2$). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.70 (m, 1 H), 1.92 (m, 3 H), 3.10 (m, 1 H), 3.34 (m, 1 H), 3.56 (m, 2 H), 3.85 (m, 1 H), 7.12 (m, 9 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, *J* = 3.8 Hz), 32.5, 46.8, 49.7 (d, *J* = 18.1 Hz), 57.1 (d, *J* = 10.5 Hz), 116.3 (d, *J* = 5.2 Hz, 2 C), 119.4 (d, *J* = 4.3 Hz), 121.7 (d, *J* = 5.2 Hz), 121.9, 125.1, 129.4 (s, 2 C), 130.2, 134.6, 141.0 (d, *J* = 5.8 Hz), 151.8 (d, *J* = 8.7 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.8. − $C_{17}H_{18}ClN_2O_2P$ (348.8): calcd. C 58.5, H 5.2, N 8.0, P 8.9; found C 58.4, H 5.1, N 8.2, P 8.8.

**(2*S*,5*S*)-2-(3-*tert*-Butylphenoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (1h):** Purification by crystallization (from ethyl acetate/petroleum ether) afforded **1h** as a white solid in 63% yield; m.p. 109°C. − $[\alpha]_D^{20}$ = −101 (*c* = 0.58, $CH_2Cl_2$). − $^1$H NMR (400 MHz, $CDCl_3$): δ = 1.17 (s, 9 H), 1.63 (m, 1 H), 1.89 (m, 3 H), 3.11 (m, 1 H), 3.36 (m, 3 H), 3.67 (m, 1 H), 6.86 (m, 1 H), 6.99 (m, 2 H), 7.25 (m, 6 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.2 (d, *J* = 4.1 Hz), 31.2 (s, 3 C), 32.5, 34.6, 46.5 (d, *J* = 2.4 Hz), 49.5 (d, *J* = 17.5 Hz), 57.0 (d, *J* = 10.2 Hz), 116.2 (d, *J* = 5.4 Hz, 2 C), 118.1 (d, *J* = 4.2 Hz), 118.5 (d, *J* = 4.4 Hz), 121.5, 121.7, 128.8, 129.3 (s, 2 C), 141.3 (d, *J* = 5.8 Hz), 150.9 (d, *J* = 8.9 Hz), 153.0. − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.4. − $C_{21}H_{27}N_2O_2P$ (370.4): calcd. C 68.1, H 7.3, N 7.6, P 8.4; found C 68.3, H 7.2, N 7.7, P 8.3.

**(2*S*,5*S*)-2-(2-Naphthoxy)-3-phenyl-1,3-diaza-2-phosphabicyclo-[3.3.0]octan-2-one (1i):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 75:25) afforded **1i** as a white solid in 77% yield (the product was obtained as a 94:6 mixture of two diastereomers). − $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.67 (m,

1 H), 1.96 (m, 3 H), 3.16 (m, 1 H), 3.38 (m, 2 H), 3.52 (m, 1 H), 3.89 (m, 1 H), 7.04 (t, $J$ = 7.1 Hz, 1 H), 7.30 (m, 8 H), 7.72 (m, 3 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.1 (d, $J$ = 2.9 Hz), 32.4 (d, $J$ = 2.7 Hz), 46.7 (d, $J$ = 2.4 Hz), 49.7 (d, $J$ = 17.4 Hz), 57.0 (d, $J$ = 10.3 Hz), 116.3 (d, $J$ = 4.4 Hz, 2 C), 117.7 (d, $J$ = 4.4 Hz), 121.3 (d, $J$ = 3.2 Hz), 121.7, 125.3, 126.5, 127.6 (d, $J$ = 8.6 Hz, 2 C), 129.4 (s, 2 C), 130.9, 133.9, 141.3 (d, $J$ = 5.4 Hz), 148.8 (d, $J$ = 9.1 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 16.9 (major) and 11.1 (minor). – $C_{21}H_{21}N_2O_2P$ (364.4): calcd. C 69.2, H 5.8, N 7.7, P 8.5; found C 69.3, H 5.6, N 7.7, P 8.4.

**General Procedure for the Preparation of Compounds 2a–j:** To a stirred solution of the appropriate compound **1a–i** (2.5 mmol) in dry THF (25 mL) under argon at −78 °C was slowly added a solution of LDA (5 mmol, 2 M in THF, 2.5 mL). The mixture was allowed to warm to room temperature and then quenched by the addition of a saturated $NH_4Cl$ solution (20 mL). The product was extracted with ethyl acetate (3 × 10 mL). The combined organic phases were dried with $MgSO_4$, filtered, and concentrated to dryness under reduced pressure. The residue was purified by flash chromatography on a silica-gel column.

**(2*S*,5*S*)-2-(2-Hydroxy-5-methoxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2a):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2a** as a white solid in 86% yield; m.p. 176 °C. – $[\alpha]_D^{20}$ = −4 ($c$ = 0.9, $CH_2Cl_2$). – $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.07 (m, 4 H), 3.05 (m, 1 H), 3.55 (m, 1 H), 3.70 (s, 3 H), 3.92 (m, 3 H), 6.19 (dd, $J$ = 8.1 Hz, $J$ = 5.8 Hz, 1 H), 6.56 (dd, $J$ = 8.3 Hz, $J$ = 5.3 Hz, 1 H), 6.87 (t, $J$ = 7.0 Hz, 1 H), 6.99 (d, $J$ = 7.8 Hz, 2 H), 7.18 (dd, $J$ = 7.8 Hz, $J$ = 7.0 Hz, 2 H), 7.23 (dd, $J$ = 5.8 Hz, $J$ = 5.3 Hz, 1 H), 12.06 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.5 (d, $J$ = 2.4 Hz), 33.5, 44.7, 49.0 (d, $J$ = 15.8 Hz), 56.1, 59.5 (d, $J$ = 7.2 Hz), 100.6 (d, $J$ = 160.1 Hz), 101.1 (d, $J$ = 7.3 Hz), 110.5 (d, $J$ = 11.3 Hz), 115.8 (d, $J$ = 4.9 Hz, 2 H), 121.4, 129.1 (s, 2 C), 134.8, 141.4 (d, $J$ = 7.2 Hz), 161.5, 164.9 (d, $J$ = 4.5 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 33.4. – $C_{18}H_{21}N_2O_3P$ (344.3): calcd. C 62.8, H 6.1, N 8.1, P 9.0; found C 62.9, H 6.2, N 8.2, P 9.0.

**(2*S*,5*S*)-2-(5-Fluoro-2-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2b):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2b** as a white solid in 76% yield; m.p. 138 °C. – $[\alpha]_D^{20}$ = +46 ($c$ = 0.33, $CH_2Cl_2$). – $^1$H NMR (400 MHz, $CDCl_3$): δ = 1.77 (m, 1 H), 2.07 (m, 3 H), 2.98 (m, 1 H), 3.55 (m, 1 H), 3.74 (m, 1 H), 4.00 (m, 2 H), 6.82 (ddd, $J$ = 16.6 Hz, $J$ = 8.1 Hz, $J$ = 3.1 Hz, 1 H), 6.87 (m, 1 H), 6.91 (t, $J$ = 7.3 Hz, 1 H), 6.98 (d, $J$ = 8.6 Hz, 2 H), 7.01 (td ≡ ddd, $J$ = 8.7 Hz, $J$ = 8.1 Hz, $J$ = 3.1 Hz, 1 H), 7.19 (dd, $J$ = 8.6 Hz, $J$ = 7.3 Hz, 2 H), 10.87 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.7 (d, $J$ = 2.4 Hz), 29.8, 44.5, 49.7 (d, $J$ = 14.3 Hz), 60.1 (d, $J$ = 5.7 Hz), 113.3 (dd, $J$ = 164.1 Hz, $J$ = 5.6 Hz), 115.2 (d, $J$ = 23.1 Hz), 116.7 (d, $J$ = 4.5 Hz, 2 C), 119.1 (dd, $J$ = 13.1 Hz, $J$ = 7.2 Hz), 121.9 (dd, $J$ = 23.1 Hz, $J$ = 2.3 Hz), 122.3, 129.4 (s, 2 C), 140.8 (d, $J$ = 7.1 Hz), 156.6 (dd, $J$ = 239 Hz, $J$ = 19.9 Hz), 159.0 (d, $J$ = 6.5 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 31.6 (d, $J$ = 5.7 Hz). – $^{19}$F NMR (94.2 MHz, $CDCl_3$): δ = −67.6. – $C_{17}H_{18}FN_2O_2P$ (332.3): calcd. C 61.4, H 5.5, N 8.4, P 9.3; found C 61.3, H 5.5, N 8.4, P 9.4.

**(2*S*,5*S*)-2-(5-Chloro-2-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2c):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2c** as a white solid in 77% yield; m.p. 146 °C. – $[\alpha]_D^{20}$ = −31 ($c$ = 1.5, $CH_2Cl_2$). – $^1$H NMR (400 MHz, $CDCl_3$): δ = 1.82 (m, 1 H), 2.05 (m, 3 H), 2.98 (m, 1 H), 3.56 (m, 1 H), 3.73 (m, 1 H), 4.00 (m, 2 H), 6.88 (dd, $J$ = 8.8 Hz, $J$ = 6.8 Hz, 1 H), 6.94 (t, $J$ = 7.3 Hz, 1 H), 6.98 (d, $J$ = 7.6 Hz, 2 H), 7.12 (dd, $J$ = 16.1 Hz, $J$ = 2.6 Hz, 1 H), 7.22 (dd, $J$ = 7.6 Hz, $J$ = 7.3 Hz, 2 H), 7.45 (dd, $J$ = 6.8 Hz, $J$ = 2.6 Hz, 1 H), 11.15 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.7, 32.3, 44.5 (d, $J$ = 2.0 Hz), 49.7 (d, $J$ = 13.0 Hz), 60.0 (d, $J$ = 5.0 Hz), 114.5 (d, $J$ = 162.0 Hz), 116.6 (d, $J$ = 5.6 Hz, 2 C), 119.4 (d, $J$ = 12.0 Hz), 122.2, 124.0 (d, $J$ = 13.2 Hz), 129.4 (s, 2 C), 130.5 (d, $J$ = 8.6 Hz), 134.3 (d, $J$ = 2.5 Hz), 140.9 (d, $J$ = 5.0 Hz), 161.5 (d, $J$ = 6.0 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 31.4. – $C_{17}H_{18}ClN_2O_2P$ (348.8): calcd. C 58.5, H 5.2, N 8.0, P 8.9; found C 58.6, H 5.3, N 8.0, P 8.8.

**(2*S*,5*S*)-2-(3,5-Di-*tert*-butyl-2-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2d):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2d** as a white solid in 76% yield; m.p. 189 °C. – $[\alpha]_D^{20}$ = +29 ($c$ = 2, $CH_2Cl_2$). – $^1$H NMR (200 MHz, $CDCl_3$): δ = 1.23 (s, 9 H), 1.48 (s, 9 H), 2.05 (m, 4 H), 3.03 (m, 1 H), 3.58 (m, 1 H), 3.95 (m, 3 H), 6.89 (t, $J$ = 7.2 Hz, 1 H), 7.01 (d, $J$ = 8.4 Hz, 2 H), 7.05 (dd, $J$ = 16.6 Hz, $J$ = 2.4 Hz, 1 H), 7.18 (dd, $J$ = 8.4 Hz, $J$ = 7.2 Hz, 2 H), 7.38 (d, $J$ = 2.4 Hz, 1 H), 11.24 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 29.5 (s, 3 C), 31.4 (s, 3 C), 32.3, 34.1, 35.2 (d, $J$ = 2.2 Hz), 44.8, 49.8 (d, $J$ = 13.1 Hz), 60.0 (d, $J$ = 4.4 Hz), 111.7 (d, $J$ = 160.4 Hz), 116.7 (d, $J$ = 4.6 Hz, 2 C), 121.6, 124.9 (d, $J$ = 7.6 Hz), 128.9 (d, $J$ = 2.4 Hz), 129.1 (s, 2 C), 137.0 (d, $J$ = 11.3 Hz), 140.6 (d, $J$ = 12.3 Hz), 141.5 (d, $J$ = 5.8 Hz), 159.7 (d, $J$ = 7.3 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 35.4. – $C_{25}H_{35}N_2O_2P$ (426.5): calcd. C 70.4, H 8.3, N 6.6, P 7.3; found C 70.4, H 8.2, N 6.5, P 7.2.

**(2*S*,5*S*)-2-(2-Hydroxy-6-methoxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2e):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2e** as a white solid in 72% yield; m.p. 171 °C. – $[\alpha]_D^{20}$ = −4 ($c$ = 0.9, $CH_2Cl_2$). – $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.07 (m, 4 H), 3.05 (m, 1 H), 3.55 (m, 1 H), 3.70 (s, 3 H), 3.92 (m, 3 H), 6.19 (dd, $J$ = 8.1 Hz, $J$ = 5.8 Hz, 1 H), 6.56 (dd, $J$ = 8.3 Hz, $J$ = 5.3 Hz, 1 H), 6.87 (t, $J$ = 7.0 Hz, 1 H), 6.99 (d, $J$ = 7.8 Hz, 2 H), 7.18 (dd, $J$ = 7.8 Hz, $J$ = 7.0 Hz, 2 H), 7.23 (t ≡ dd, $J$ = 8.3 Hz, $J$ = 8.1 Hz, 1 H), 12.06 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.5 (d, $J$ = 2.4 Hz), 33.5, 44.7, 49.0 (d, $J$ = 15.8 Hz), 56.1, 59.5 (d, $J$ = 7.2 Hz), 100.6 (d, $J$ = 160.1 Hz), 101.1 (d, $J$ = 7.3 Hz), 110.5 (d, $J$ = 11.3 Hz), 115.8 (d, $J$ = 4.9 Hz, 2 C), 121.4, 129.1 (s, 2 C), 134.8, 141.4 (d, $J$ = 7.2 Hz), 161.5, 164.9 (d, $J$ = 4.5 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 33.4. – $C_{18}H_{21}N_2O_3P$ (344.3): calcd. C 62.8, H 6.1, N 8.1, P 9.0; found C 62.7, H 6.1, N 8.0, P 9.1.

**(2*S*,5*S*)-2-(2-Fluoro-6-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2f):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2f** as a white solid in 85% yield; m.p. 208 °C. – $[\alpha]_D^{20}$ = +35 ($c$ = 0.10, $CH_2Cl_2$). – $^1$H NMR (200 MHz, $CDCl_3$): δ = 2.02 (m, 4 H), 3.01 (m, 1 H), 3.54 (m, 1 H), 3.75 (m, 1 H), 4.02 (m, 2 H), 6.38 (dddd, $J$ = 9.8 Hz, $J$ = 8.1 Hz, $J$ = 5.2 Hz, $J$ = 0.9 Hz, 1 H), 6.72 (dd, $J$ = 8.4 Hz, $J$ = 5.0 Hz, 1 H), 6.91 (t, $J$ = 7.2 Hz, 1 H), 7.02 (d, $J$ = 7.7 Hz, 2 H), 7.20 (dd, $J$ = 7.7 Hz, $J$ = 7.2 Hz, 2 H), 7.25 (m, 1 H), 11.75 (s, 1 H). – $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.6, 32.9, 44.4, 48.6 (dd, $J$ = 15.9 Hz, $J$ = 4.3 Hz), 59.1 (d, $J$ = 7.4 Hz), 101.5 (dd, $J$ = 159.3 Hz, $J$ = 18.9 Hz), 105.6 (dd, $J$ = 22.9 Hz, $J$ = 6.2 Hz), 113.4 (dd, $J$ = 10.2 Hz, $J$ = 2.8 Hz), 116.3 (d, $J$ = 5.4 Hz, 2 C), 122.0, 129.2 (s, 2 C), 134.8 (d, $J$ = 11.9 Hz), 140.8 (d, $J$ = 6.9 Hz), 163.5 (d, $J$ = 246 Hz), 164.2 (t ≡ dd, $J$ = 2.9 Hz, $J$ = 2.9 Hz). – $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 28.7 (d, $J$ = 5.7 Hz). – $^{19}$F NMR (94.2 MHz, $CDCl_3$): δ = −85.6. –

$C_{17}H_{18}FN_2O_2P$ (332.3): calcd. C 61.4, H 5.5, N 8.4, P 9.3; found C 61.3, H 5.6, N 8.5, P 9.2.

**(2*S*,5*S*)-2-(2-Chloro-6-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2g):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2g** as a white solid in 92% yield; m.p. 174°C. − $[\alpha]_D^{20}$ = +50 (*c* = 0.95, $CH_2Cl_2$). − $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.10 (m, 4 H), 3.00 (m, 1 H), 3.57 (m, 1 H), 3.73 (m, 1 H), 4.09 (m, 2 H), 6.75 (ddd, *J* = 7.7 Hz, *J* = 4.7 Hz, *J* = 1.0 Hz, 1 H), 6.88 (ddd, *J* = 8.5 Hz, *J* = 4.8 Hz, *J* = 1.0 Hz, 1 H), 6.92 (t, *J* = 7.4 Hz, 1 H), 6.98 (dd, *J* = 8.1 Hz, *J* = 0.7 Hz, 2 H), 7.20 (dd, *J* = 8.1 Hz, *J* = 7.4 Hz, 2 H), 7.23 (dd, *J* = 4.8 Hz, *J* = 4.7 Hz, 1 H), 12.52 (s, 1 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.6 (d, *J* = 2.6 Hz), 33.7, 44.2, 49.2 (d, *J* = 15.1 Hz), 60.0 (d, *J* = 7.2 Hz), 109.7 (d, *J* = 165.0 Hz), 116.2 (d, *J* = 5.6 Hz, 2 C), 116.9 (d, *J* = 10.1 Hz), 121.3 (d, *J* = 8.4 Hz), 122.1, 129.3 (s, 2 C), 134.4, 136.7, 140.5 (d, *J* = 7.2 Hz), 165.9 (d, *J* = 5.7 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 31.6. − $C_{17}H_{18}ClN_2O_2P$ (348.8): calcd. C 58.5, H 5.2, N 8.0, P 8.9; found C 58.4, H 5.2, N 8.1, P 8.9.

**(2*S*,5*S*)-2-(4-*tert*-Butyl-2-hydroxyphenyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2h):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2h** as a white solid in 84% yield; m.p. 201°C. − $[\alpha]_D^{20}$ = +20.2 (*c* = 1.05, $CH_2Cl_2$). − $^1$H NMR (400 MHz, $CDCl_3$): δ = 1.26 (s, 9 H), 1.78 (m, 1 H), 1.94 (m, 1 H), 2.05 (m, 1 H), 2.15 (m, 1 H), 6.80 (ddd, *J* = 8.2 Hz, *J* = 2.6 Hz, *J* = 1.8 Hz, 1 H), 6.89 (t, *J* = 7.4 Hz, 1 H), 6.94 (dd, *J* = 6.1 Hz, *J* = 1.8 Hz, 1 H), 6.98 (dd, *J* = 7.8 Hz, *J* = 0.8 Hz, 2 H), 7.08 (dd, *J* = 15.5 Hz, *J* = 8.2 Hz, 1 H), 7.18 (dd, *J* = 7.8 Hz, *J* = 7.4 Hz, 2 H), 10.97 (s, 1 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.7, 31.0 (s, 3 C), 32.4, 35.0, 44.6, 49.8 (d, *J* = 14.1 Hz), 59.8 (d, *J* = 5.2 Hz), 109.7 (d, *J* = 166.7 Hz), 114.5 (d, *J* = 11.5 Hz), 116.5 (d, *J* = 5.6 Hz, 2 C), 117.3 (d, *J* = 14.3 Hz), 121.7, 129.3 (s, 2 C), 131.0 (d, *J* = 7.8 Hz), 141.4 (d, *J* = 5.9 Hz), 158.4 (d, *J* = 2.8 Hz), 162.7 (d, *J* = 7.3 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 35.2. − $C_{21}H_{27}N_2O_2P$ (370.4): calcd. C 68.1, H 7.3, N 7.6, P 8.4; found C 68.1, H 7.2, N 7.7, P 8.5.

**(2*S*,5*S*)-2-(2-Hydroxy-1-naphthyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2i) and (2*S*,5*S*)-2-(3-Hydroxy-2-naphthyl)-3-phenyl-1,3-diaza-2-phosphabicyclo[3.3.0]octan-2-one (2j):** Purification by column chromatography (silica gel; ethyl acetate/petroleum ether, 33:66) afforded **2i** and **2j** as white solids in 78% combined yield. − **2i**: M.p. 270°C. − $[\alpha]_D^{20}$ = −10 (*c* = 0.65, $CH_2Cl_2$). − $^1$H NMR (400 MHz, $CDCl_3$): δ = 1.82 (m, 1 H), 1.96 (m, 1 H), 2.15 (m, 1 H), 2.23 (m, 1 H), 2.92 (m, 1 H), 3.74 (m, 2 H), 4.19 (m, 1 H), 4.27 (m, 1 H), 6.82 (t, *J* = 7.3 Hz, 1 H), 6.95 (d, *J* = 8.5 Hz, 2 H), 7.09 (dd, *J* = 8.5 Hz, *J* = 7.3 Hz, 2 H), 7.13 (dd, *J* = 8.0 Hz, *J* = 5.6 Hz, 1 H), 7.24 (dd, *J* = 8.7 Hz, *J* = 6.8 Hz, 1 H), 7.39 (dd, *J* = 8.3 Hz, *J* = 7.2 Hz, 1 H), 7.65 (d, *J* = 8.0 Hz, 1 H), 7.81 (d, *J* = 8.7 Hz, 2 H), 13.11 (s, 1 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.9, 33.3, 44.2, 49.7 (d, *J* = 14.3 Hz), 60.2 (d, *J* = 5.0 Hz), 100.2 (d, *J* = 163.6 Hz), 116.7 (d, *J* = 4.7 Hz, 2 C), 120.4 (d, *J* = 13.3 Hz), 122.0, 123.0 (s, 2 C), 127.5 (s, 2 C), 128.4, 129.2 (s, 2 C), 133.9 (d, *J* = 7.1 Hz), 136.1, 140.9 (d, *J* = 6.9 Hz), 166.2 (d, *J* = 7.2 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 34.3. − $C_{21}H_{21}N_2O_2P$ (364.4): calcd. C 69.2, H 5.8, N 7.7, P 8.5; found C 69.2, H 5.9, N 7.7, P 8.6. − **2j**: M.p. 262°C. − $[\alpha]_D^{20}$ = −123 (*c* = 0.65, $CH_2Cl_2$). − $^1$H NMR (400 MHz, $CDCl_3$): δ = 2.08 (m, 4 H), 3.00 (m, 1 H), 3.63 (m, 1 H), 3.80 (m, 1 H), 4.08 (m, 2 H), 6.88 (t, *J* = 7.3 Hz, 1 H), 7.04 (d, *J* = 8.4 Hz, 2 H), 7.15 (dd, *J* = 8.4 Hz, *J* = 7.3 Hz, 2 H), 7.21 (dd, *J* = 7.9 Hz, *J* = 7.5 Hz, 1 H), 7.28 (d, *J* = 6.2 Hz, 1 H), 7.39 (dd, *J* = 7.9 Hz, *J* = 7.4 Hz, 1 H), 7.63 (d, *J* = 8.7 Hz, 2 H), 7.81 (d, *J* = 17.8 Hz, 1 H), 11.75 (s, 1 H). − $^{13}$C NMR (50 MHz, $CDCl_3$): δ = 26.8, 32.4, 44.6, 49.8 (d, *J* = 13.4 Hz), 60.1 (d, *J* = 5.7 Hz), 111.6 (d, *J* = 11.3 Hz), 116.5 (d, *J* = 5.5 Hz, 2 C), 116.7 (d, *J* = 161.9 Hz), 122.0, 123.6, 126.4, 127.5 (d, *J* = 14.5 Hz), 128.4 (d, *J* = 13.1 Hz, 2 C), 129.4 (s, 2 C), 133.8 (d, *J* = 7.3 Hz), 137.4 (d, *J* = 2.6 Hz), 141.1 (d, *J* = 7.1 Hz), 157.9 (d, *J* = 7.3 Hz). − $^{31}$P NMR (40.5 MHz, $CDCl_3$): δ = 32.3. − $C_{21}H_{21}N_2O_2P$ (364.4): calcd. C 69.2, H 5.8, N 7.7, P 8.5; found C 69.2, H 5.7, N 7.6, P 8.4.

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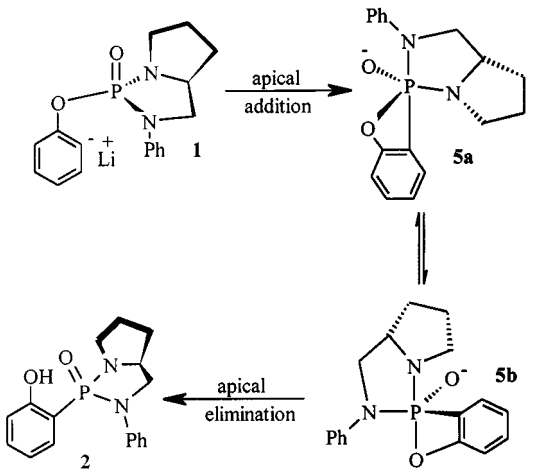


Scheme 3. Mechanism for the stereoselective P−O-to-P−C rearrangement

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[16] In the case of the **1a** rearrangement, we did not observe the formation of the *P*-(*m*-hydroxyaryl)diazaphospholidine *P*-oxide adduct **2a′**. The latter might have resulted from an *ortho*-directed metallation followed by an intermolecular nucleophilic substitution on the phosphoryl group.

[17] **X-ray analysis of 2b:** A single white plate of $C_{17}H_{18}FN_2O_2P$ of approximate dimensions $0.6 \times 0.3 \times 0.3$ mm, obtained by recrystallization from ethyl acetate, was mounted on a glass capillary. All measurements were made with a Rigaku diffractometer using Mo-$K_\alpha$ radiation. Cell constants and the orientation matrix for data collection were obtained from a least-squares refinement using setting angles of 30 reflections in the range $\theta = 1-25°$, which corresponded to an orthorhombic cell with dimensions: $a = 6.719(1)$, $b = 11.125(1)$, $c = 21.949(1)$ Å. For $Z = 4$ and $M_r = 332.31$, $\rho_{calcd.} = 1.35$ g cm$^{-3}$. The space group was determined as $P2_12_12_1$ from the systematic absences. A total of 1635 reflections were collected at $T = 298$ K. The standards were measured after every 120 reflections. Among the first 200 pairs of reflections, the signs of the corresponding calculated differences established that the molecule had been described with the correct absolute configuration (*S*).

[18] **X-ray analysis of 2f:** A single white plate of $C_{17}H_{18}FN_2O_2P$ of approximate dimensions $0.7 \times 0.4 \times 0.4$ mm, obtained by recrystallization from ethyl acetate, was mounted on a glass capillary. All measurements were made with a Rigaku diffractometer using Mo-$K_\alpha$ radiation. Cell constants and the orientation matrix for data collection were obtained from a least-squares refinement using setting angles of 30 reflections in the range $\theta = 1-25°$, which corresponded to an orthorhombic cell with dimensions: $a = 9.031(1)$, $b = 10.466(1)$, $c = 16.862(1)$ . For $Z = 4$ and $M_r = 332.31$, $\rho_{calcd.} = 1.39$ g cm$^{-3}$. The space group was determined as $P2_12_12_1$ from the systematic absences. A total of 1749 reflections were collected at $T = 298$ K. The standards were measured after every 120 reflections. Among the first 200 pairs of reflections, the signs of the corresponding calculated differences established that the molecule had been described with the correct absolute configuration (*S*).

[19] Such a lack of regioselectivity in a 1,3-migration of the P$^{IV}$ group from a heteroatom to a naphthalene ring has previously been observed on treatment of diethyl (2-naphthyl)phosphate with excess LDA at −78°C.[4c]

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