
VOLUME 29 ISSUE 2
MARCH–APRIL 2019
PAGES 121–236
ISSN 0959–9436
Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Mendeleev
Communications
Preliminary accounts
of new works in chemistry
from Russia and elsewhere
Russian
Academy of Sciences

Available online at www.sciencedirect.com
ScienceDirect
Mendeleev Commun., 2019, **29**, 150–152

Mendeleev Communications

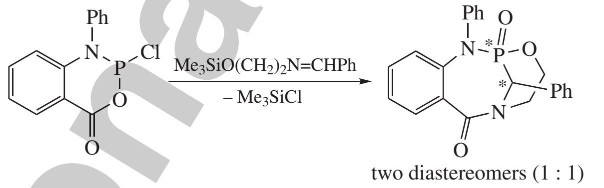
Synthesis and structure of stereoisomers of 3,4-benzo-5,10-diphenyl-1,3-diaza-7-oxa-6-phosphabicyclo[4.3.1]decane-2,6-dione

Mudaris N. Dimukhametov,[a] Gulnara A. Ivkova,[b] Igor A. Litvinov,[a] Robert R. Fayzullin[a] and Vladimir F. Mironov*[a,b]

[a] *A. E. Arbuzov Institute of Organic and Physical Chemistry, FRC Kazan Scientific Center of the Russian Academy of Sciences, 420088 Kazan, Russian Federation. E-mail: mironov@iopc.ru*
[b] *A. M. Butlerov Institute of Chemistry, Kazan Federal University, 420008 Kazan, Russian Federation*

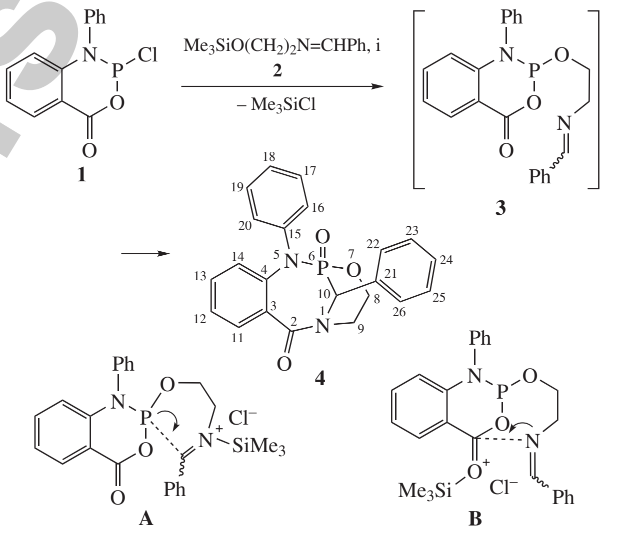
DOI: 10.1016/j.mencom.2019.03.010

A mild approach to the synthesis of the title cage aminophosphonate has been developed based on the intramolecular cyclization of 2-(2-benzylideneaminoethoxy)-1-phenylbenzo-[*e*]-1,3,2-azaoxaphosphorin-4-one obtained from 1-phenyl-2-chlorobenzo[*e*]-1,3,2-azaoxaphosphorin-4-one and (2-benzylideneaminoethoxy)trimethylsilane. The structure of isolated diastereomers of the product was determined by NMR spectroscopy and single crystal X-ray diffraction analysis.



α-Aminophosphonic acids have useful properties such as biological activity[1] and capability to form complexes with several metals.[2] The Kabachnik–Fields and Pudovik reactions[3] provide versatile and popular approach to the synthesis of these compounds. Previously, we suggested to obtain 1-aminophosphonic acid esters by ring expansion reaction of 2-substituted benzo[*e*]-1,2,3-dioxaphosphorin-4-ones, containing the P–O–C(O) high-energy moiety, with imines. This approach resulted in only one of the two possible diastereomers of 3,4-dihydrobenzo[*f*]-1,4,2-oxazaphosphepine-2,5-diones with high selectivity.[4] The intramolecular version of this reaction carried out with 2-(2-arylmethylideneaminophenoxy)benzo[*e*]-1,3,2-dioxaphosphorin-4-ones, containing a C=N exocyclic bond, allowed us to obtain cage α-aminophosphonates with high stereoselectivity.[5]

In this study, we successfully implemented a new modification of this intramolecular approach to the synthesis of cage aminophosphonates using the reaction of 2-chloro-1-phenylbenzo[*e*]-1,3,2-azaoxaphosphorin-4-one **1** with (2-benzylideneaminoethoxy)trimethylsilane **2** (Scheme 1).† The formation of P^{III} derivative, 2-(2-benzylideneaminoethoxy)-1-phenylbenzo[*e*]-1,3,2-azaoxaphosphorin-4-one **3**, was detected by ^{31}P NMR (*δ* 120.3 ppm). Compound **3** was unstable under the reaction conditions and was immediately converted into the bicyclic cage aminophosphonate **4** as 1 : 1 diastereomeric mixture.‡ Lack in stability for compound **3** as compared to 2-(2-benzylidene-



Scheme 1 *Reagents and conditions*: i, CH_2Cl_2, 25 °C, 4 h.

† *(2-Benzylideneaminoethoxy)trimethylsilane* **2**. A solution of chlorotrimethylsilane (8.1 g, 74.7 mmol) in diethyl ether (20 ml) was added dropwise to a mixture of 2-(benzylideneamino)ethanol (11.1 g, 74.5 mmol) and triethylamine (7.6 g, 75.3 mmol) in dry diethyl ether (100 ml) at 20 °C under an argon atmosphere, and the mixture was left overnight. The formed precipitate was filtered off, the volatiles from the filtrate were removed *in vacuo* and the residue was distilled. Yield 12.4 g (75%), light-yellow liquid, bp 171–173 °C (15 Torr), n_D^{20} = 1.5097. ^{1}H NMR (600 MHz, $CDCl_3$) *δ*: 0.11 (s, 9H, Me_3Si), 3.75 (t, 2H, NCH_2, ^3J 5.8 Hz), 3.91 (t, 2H, OCH_2, ^3J 5.8 Hz), 7.41 (m, 3H, *m*-H, *p*-H), 7.74 (m, 2H, *o*-H), 8.28 (s, 1H, =CH). Compound **2** was previously obtained as a crude material by different procedure.[8]

‡ *3,4-Benzo-5,10-diphenyl-1,5-diaza-7-oxa-6-phosphabicyclo[4.3.1]-decane-2,6-dione* **4**. A solution of 2-chloro-1-phenylbenzo[*e*]-1,3,2-azaoxaphosphorin-4-one **1** (1.53 g, 5.5 mmol) in dichloromethane (10 ml) was added dropwise to the solution of the trimethylsilane **2** in dichloromethane (20 ml) at 20 °C under stirring for 5 min. The reaction mixture that immediately acquired a bright crimson colour was left overnight. Then volatile components were removed *in vacuo* (12 Torr). The residue was treated with diethyl ether and dried *in vacuo* to give a light red powder of product **4** as 1 : 1 mixture of diastereomers d_1 and d_2. Yield 1.82 g (85%). MS (EI), *m/z* (%): 390 $[M]^{•+}$ (83.9), 362 $[M-C_2H_4]^+$ (19.4), 313 $[M-C_6H_5]^+$ (66.8), 299 $[M-P(O)OC_2H_4]^+$ (18.6), 285 $[C_{20}H_{17}N_2]^+$ (2.9), 195 $[C_8H_8N_2O_2P]^+$ (100.0), 167 $[C_7H_8N_2OP]^+$ (58.9), 91 $[C_6H_5CH_2]^+$ (23.5), 77 $[C_6H_5]^+$ (28.4). Found (%): C, 67.28; H, 5.21; N, 7.09; P, 7.88. Calc. for $C_{22}H_{19}N_2O_3P$ (%): C, 67.69; H, 4.87; N, 7.18; P, 7.95. Air-stable individual diastereomers **4**(d_1) [0.85 g, mp 263–264°C (decomp.), δ_P: 15.3 ppm] and **4**(d_2) [0.74 g, mp 259–260 °C (decomp.), δ_P: 18.5 ppm] were sequentially isolated by chromatography on silica gel with chloroform and then chloroform–acetonitrile (5 : 1).

aminophenoxy)benzo[*e*]-1,3,2-dioxaphosphorin-4-one with a similar structure[5] may be explained by the effect of chlorotrimethylsilane formed in the reaction, namely the activation of both the imine moiety (see Scheme 1, structure **A**) and the carbonyl group of **3** (see Scheme 1, structure **B**). Similar activation in polar acetonitrile by an equimolar amount or excess of chlorotrimethylsilane was demonstrated earlier for diethyl phosphite[6] or triethyl phosphite[7] addition to carbonyl compounds and imines.

The structure of the isolated diastereomers of product **4** was determined by NMR spectroscopy.§ The bicyclodecane moiety was deduced from the spin–spin coupling constants in the ^{13}C and ^{13}C-{^{1}H} NMR spectra for the carbon atoms located at a distance of 1–4 bonds from the phosphorus atom. There is a noticeable difference for the chemical shifts of the H-8AB and H-9AB protons, as well as for the C^3, C^4, C^9, C^{10}, C^{14}, C^{21} and $C^{22,26}$ carbons in diastereomers d_1 and d_2, resulting from the different arrangement of the phenyl substituent at C^{10} with respect to the plane of the phenylene and oxazaphosphorinane moieties. In fact, for d_1 the difference in the chemical shifts between the H-9A and H-9B protons reaches 1.05 ppm, while it is 1.33 ppm for the d_2 counterpart. The C^4, $C^{22,26}$ and C^{24} carbons are considerably shielded in d_2 in comparison with d_1, whereas the C^3, C^9, C^{10} and C^{21} carbons are noticeably deshielded in d_2. These differences can be interpreted based on the assumption that the C^{10} carbon atom in diastereomer d_2 has a configuration where the six-membered oxazaphosphorine ring bears an equatorial phenyl moiety that overhangs the phenylene substituent, whereas diastereomer d_1 has a configuration with an axial phenyl in this six-membered ring. The NMR-based assignment of the diastereomers structure was further confirmed by single crystal X-ray diffraction data for both isolated compounds (Figure 1).¶

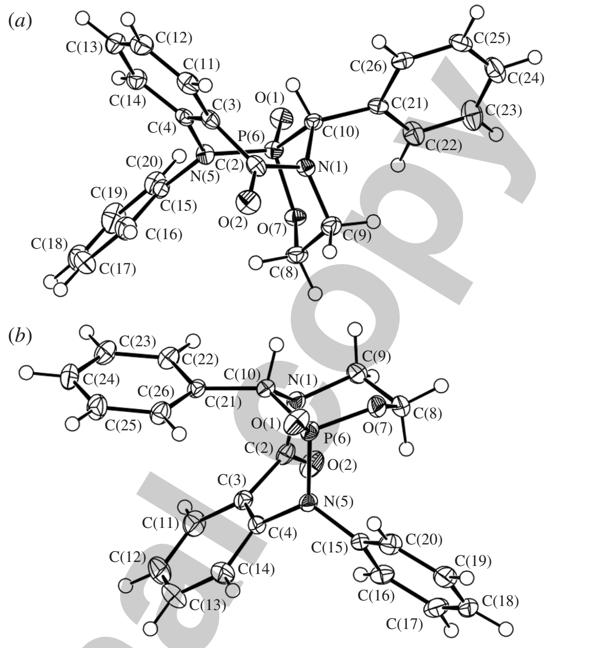


Figure 1 Molecular structures of (*a*) compound **4**(d_1) in the crystal, only the ($R_{\rm P}$,$R_{\rm C(10)}$)-enantiomer of the racemic mixture is shown; (*b*) compound **4**(d_2) in the crystal, only the ($S_{\rm P}$,$R_{\rm C(10)}$)-enantiomer of the racemic mixture is shown. Non-hydrogen atoms are presented as thermal ellipsoids with 50% probability.

The seven-membered heterocycles of the bicyclodecane cage in both diastereomers have a boat conformation [the N(1)–C(2)–N(5)–P(6) moiety is planar within 0.053(1) Å for d_1 and 0.047(2) Å

§ *Compound* **4**(d_1). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 3.24 (ddd, 1H, NC^9H_X, $^{2}J_{\rm HH}$ 14.8, 12.9, 3.7 Hz), 4.02 (ddd, 1H, POC^8H_B, $^{3}J_{\rm POCH}$ 19.2 Hz, $^{2}J_{\rm HH}$ 11.3, 3.7 Hz), 4.29–4.31 (m, 2H, POC^8H_A, NC^9H_A), 5.48 (d, 1H, PCH, $^{2}J_{\rm PCH}$ 12.1 Hz), 7.16 (m, 1H, H-12, $^{3}J_{\rm HH}$ 7.9, 7.3 Hz), 7.30 and 7.39–7.44 (two m, 11H, H-11, H-13, H-14, H-16 to H-20, H-22, H-26, H-24), 7.91 (m, 2H, H-23, H-25, $^{3}J_{\rm HH}$ 8.0, 7.6 Hz). ^{13}C NMR (100.6 MHz, $CDCl_3$, hereinafter multiplicity for signal in ^{13}C-{^{1}H} NMR is given after a slash) δ: 172.30 (m/s, C^2, $^{3}J_{\rm HC^{11}CC}$ 3.8 Hz, $^{3}J_{\rm HCNC}$ 3.8–4.0 Hz), 132.71 (br. dd/s, C^3, $^{3}J_{\rm HC^{12}CC}$ 8.4 Hz, $^{3}J_{\rm HC^{14}CC}$ 5.5 Hz), 141.25 (m/d, C^4, $^{3}J_{\rm HC^{13}CC}$ 11.5 Hz, $^{3}J_{\rm HC^{11}CC}$ 8.3 Hz, $^{2}J_{\rm PNC}$ 3.7 Hz, $^{2}J_{\rm HC^{14}C}$ 2.0 Hz), 71.62 (ddddd/d, C^8, $^{1}J_{\rm H_AC}$ 150.3 Hz, $^{1}J_{\rm H_BC}$ 152.0 Hz, $^{2}J_{\rm POC}$ 11.1 Hz, $^{2}J_{\rm H_AC^8C}$ 4.8 Hz, $^{2}J_{\rm H_BC^8C}$ 2.1 Hz), 40.52 (dddt/d, C^9, $^{1}J_{\rm H_AC}$ 142.1 Hz, $^{1}J_{\rm H_BC}$ 144.1 Hz, $^{3}J_{\rm POCC}$ 3.5 Hz, $^{2}J_{\rm HCC}$ 3.5 Hz), 55.74 (dddt/d, C^{10}, $^{1}J_{\rm HC}$ 136.4 Hz, $^{1}J_{\rm PC}$ 126.0 Hz, $^{1}J_{\rm H_AC^9NC}$ 4.8 Hz, $^{3}J_{\rm HC^{22,26}CC}$ 4.8 Hz), 128.95 (br. dd/d, C^{11}, $^{4}J_{\rm PNC^4C^3C}$ 3.3 Hz), 128.04 (br. dd/d, C^{12}, $^{1}J_{\rm HC}$ 164.8 Hz, $^{3}J_{\rm HC^{14}CC}$ 8.2 Hz, $^{5}J_{\rm PNCC^3C^{11}C}$ 1.3 Hz), 132.83 (br. dd/s, C^{13}, $^{1}J_{\rm HC}$ 162.2 Hz, $^{3}J_{\rm HC^{11}CC}$ 8.5 Hz), 127.54 (br. dd/d, C^{14}, $^{1}J_{\rm HC}$ 164.2 Hz, $^{3}J_{\rm HC^{12}CC}$ 7.6 Hz, $^{3}J_{\rm PNCC}$ 1.6 Hz), 141.99 (ttd/d, C^{15}, $^{3}J_{\rm HC^{17,19}CC}$ 9.4 Hz, $^{2}J_{\rm PNC}$ 1.8 Hz, $^{2}J_{\rm HC^{16,20}C}$ 1.5 Hz), 125.07 (dm/d, $C^{16,20}$, $^{1}J_{\rm HC}$ 161.8 Hz, $^{3}J_{\rm HC^{18}CC}$ 7.8 Hz, $^{3}J_{\rm HC^{20,16}CC}$ 7.3–7.5 Hz, $^{3}J_{\rm PNC^{15}C}$ 3.0 Hz), 129.15 (dd/s, $C^{17,19}$, $^{1}J_{\rm HC}$ 160.6 Hz, $^{3}J_{\rm HC^{19,17}CC}$ 7.7 Hz), 125.68 (dt/s, C^{18}, $^{1}J_{\rm HC}$ 160.4, $^{3}J_{\rm HC^{16,20}CC}$ 7.7 Hz), 130.90 (tdd/d, C^{21}, $^{3}J_{\rm HC^{23,25}CC}$ 7.8 Hz, $^{2}J_{\rm HC^{10}C}$ 7.8 Hz, $^{2}J_{\rm PC^{10}C}$ 4.2 Hz), 128.95 (dm/d, $C^{22,26}$, $^{1}J_{\rm HC}$ 161.9 Hz, $^{3}J_{\rm PC^{10}C^{21}C}$ 7.9 Hz, $^{3}J_{\rm HC^{24}CC}$ 7.6 Hz, $^{3}J_{\rm HC^{26,22}CC}$ 7.2 Hz), 129.67 (dd/s, $C^{23,25}$, $^{1}J_{\rm HC}$ 162.0 Hz, $^{3}J_{\rm HC^{25,23}CC}$ 8.2 Hz), 128.78 (dt/s, C^{24}, $^{1}J_{\rm HC}$ 161.1 Hz, $^{3}J_{\rm HC^{22,26}CC}$ 7.3 Hz). ^{31}P/^{31}P-{^{1}H} NMR (162.0 MHz, $CDCl_3$) δ: 15.4 (dd/s, $^{3}J_{\rm POCH}$ 19.4 Hz, $^{2}J_{\rm PCH}$ 12.3 Hz).

Compound **4**(d_2). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 3.58 (ddd, 1H, NC^9H_B, $^{2}J_{\rm HH}$ 14.2 Hz, $^{3}J_{\rm HH}$ 12.3, 3.7 Hz), 4.22 (ddd, 1H, POC^8H_B, $^{3}J_{\rm POCH}$ 20.3 Hz, $^{2}J_{\rm HH}$ 11.6 Hz, $^{3}J_{\rm HH}$ 3.7 Hz), 4.34 (dddd, 1H, $POCH_A$, $^{2}J_{\rm HH}$ 11.6 Hz, $^{3}J_{\rm HH}$ 12.3, 2.9 Hz, $^{3}J_{\rm POCH}$ 1.9 Hz), 4.89 (dd, 1H, NC^9H_B, $^{2}J_{\rm HH}$ 14.2 Hz, $^{3}J_{\rm HH}$ 2.9 Hz), 5.38 (d, 1H, PCH, $^{2}J_{\rm PCH}$ 21.0 Hz), 6.81 (br. dd, 1H, H-12, $^{3}J_{\rm HH}$ 8.1, 7.4 Hz), 6.95 (dd, 1H, H-11, $^{3}J_{\rm HH}$ 7.7 Hz, $^{4}J_{\rm HH}$ 1.6 Hz), 6.98 (br. d, 1H, H-14, $^{3}J_{\rm HH}$ 8.1 Hz), 7.03–7.05 (m, 3H, H-18, H-16, H-20, $^{3}J_{\rm HH}$ 7.4 Hz), 7.14 (br. dd, 1H, H-13, $^{3}J_{\rm HH}$ 7.9, 7.4 Hz), 7.18 (br. t, 1H, H-24, $^{3}J_{\rm HH}$ 7.1 Hz), 7.32–7.37 (m, 6H, H-17, H-19, H-22, H-26, H-23, H-25). ^{13}C/^{13}C-{^{1}H} NMR (100.6 MHz, $CDCl_3$) δ: 172.80 (m/s, C^2, $^{3}J_{\rm HC^{10}NC}$ 6.8 Hz, $^{3}J_{\rm HC^9NC}$ 6.6 Hz, $^{3}J_{\rm HC^{11}CC}$ 3.8 Hz), 135.45 (br. dd/s, C^3, $^{3}J_{\rm HC^{12}CC}$ 8.6 Hz, $^{3}J_{\rm HC^{14}CC}$ 5.6 Hz), 138.70 (m/d, C^4, $^{3}J_{\rm HC^{13}CC}$ 11.5 Hz, $^{3}J_{\rm HC^{11}CC}$ 8.3 Hz, $^{2}J_{\rm PNC}$ 5.1 Hz, $^{2}J_{\rm HC^{14}C}$ 2.0 Hz), 71.63 (ddddd/d, C^8, $^{1}J_{\rm H_AC}$ 153.3 Hz, $^{1}J_{\rm H_BC}$ 149.6 Hz, $^{2}J_{\rm POC}$ 11.8 Hz, $^{2}J_{\rm H_AC^9C}$ 4.6 Hz, $^{2}J_{\rm H_BC^9C}$ 2.5 Hz), 50.72 (br. ddm/br. s, C^9, $^{1}J_{\rm H_AC}$ 142.0 Hz, $^{1}J_{\rm H_BC}$ 143.5 Hz, $^{2}J_{\rm H_AC^8C}$ 2.0 Hz, $^{2}J_{\rm H_BC^8C}$ 2.9 Hz), 62.49 (dddt/d, C^{10}, $^{1}J_{\rm HC}$ 134.0 Hz, $^{1}J_{\rm PC}$ 125.4 Hz, $^{1}J_{\rm H_AC^9NC}$ 5.9 Hz, $^{3}J_{\rm HC^{22,26}CC}$ 5.9–6.0 Hz), 128.38 (br. dd/d, C^{11}, $^{4}J_{\rm PNC^4C^3C}$ 3.4 Hz), 128.40 (br. dd/d, C^{12}, $^{1}J_{\rm HC}$ 164.5 Hz, $^{3}J_{\rm HC^{14}CC}$ 7.8 Hz, $^{5}J_{\rm PNCC^3C^{11}C}$ 1.2 Hz), 132.03 (br. dd/s, C^{13}, $^{1}J_{\rm HC}$ 162.2 Hz, $^{3}J_{\rm HC^{11}CC}$ 8.5 Hz), 127.26 (br. dd/d, C^{14}, $^{1}J_{\rm HC}$ 163.2 Hz, $^{3}J_{\rm HC^{12}CC}$ 7.9 Hz, $^{3}J_{\rm PNC^4C}$ 1.5 Hz), 142.06 (ttd/d, C^{15}, $^{3}J_{\rm HC^{17,19}CC}$ 9.6 Hz, $^{2}J_{\rm PNC}$ 1.6 Hz, $^{2}J_{\rm HC^{16,20}C}$ 1.5 Hz), 124.49 (dm/d, $C^{16,20}$, $^{1}J_{\rm HC}$ 161.7 Hz, $^{3}J_{\rm HC^{18}CC}$ 7.7 Hz, $^{3}J_{\rm HC^{20,16}CC}$ 7.3–7.5 Hz, $^{3}J_{\rm PNC^{15}C}$ 3.2 Hz), 128.44 (dd/s, $C^{17,19}$, $^{1}J_{\rm HC}$ 160.8 Hz, $^{3}J_{\rm HC^{19,17}CC}$ 7.6 Hz), 125.57 (dt/s, C^{18}, $^{1}J_{\rm HC}$ 164.8 Hz, $^{3}J_{\rm HC^{16,20}CC}$ 7.5 Hz), 133.79 (tdd/d, C^{21}, $^{2}J_{\rm HC^{10}C}$ 8.3 Hz, $^{3}J_{\rm HC^{23,25}CC}$ 7.5 Hz, $^{2}J_{\rm PC^{10}C}$ 2.0 Hz), 126.27 (dm/d, $C^{22,26}$, $^{1}J_{\rm HC}$ 159.0 Hz, $^{3}J_{\rm PC^{10}C^{21}C}$ 7.0 Hz, $^{3}J_{\rm HC^{24}CC}$ 7.0 Hz, $^{3}J_{\rm HC^{26,22}CC}$ 6.6–7.2 Hz), 129.77 (dd/s, $C^{23,25}$, $^{1}J_{\rm HC}$ 161.8 Hz, $^{3}J_{\rm HC^{25,23}CC}$ 7.9 Hz), 127.47 (dt/s, C^{24}, $^{1}J_{\rm HC}$ 161.5 Hz, $^{3}J_{\rm HC^{22,26}CC}$ 7.8 Hz). ^{31}P/^{31}P-{^{1}H} NMR (162.0 MHz, $CDCl_3$) δ: 18.6 (dd/s, $^{3}J_{\rm POCH}$ 21.1 Hz, $^{2}J_{\rm PCH}$ 20.2 Hz).

¶ X-ray diffraction data for the single crystals of **4**(d_1) and **4**(d_2) were collected in an ω/φ-scan mode on a Bruker Kappa Apex II CCD diffractometer equipped with an Oxford Cryostream LT device using graphite-monochromated MoKα (0.71073 Å) radiation at 150(2) K. Data were corrected for absorption based on the Laue symmetry using equiva-lent reflections as well as for systematic errors. The structures were solved by the direct method using SHELXT-2018/2[9] and refined by the full-matrix least-squares on F^2 using SHELXL-2018/3.[10] Non-hydrogen atoms were refined anisotropically. Hydrogen atoms were inserted at the calculated positions and refined as riding atoms.

Crystal data for **4**(d_1). $C_{22}H_{19}N_2O_3P$, M = 390.36, monoclinic, $P2_1/c$ (no. 14), a = 8.5028(6), b = 24.973(2) and c = 9.0183(7) Å, β = 102.140(4)°, V = 1872.1(3) Å^3, Z = 4, Z' = 1, $d_{\rm calc}$ = 1.385 g cm^{-3}, μ = = 0.173 mm^{-1}, F(000) = 816, $T_{\rm max/min}$ = 0.7116/0.6386; 11798 reflections were collected (3.103° $\leqslant \theta \leqslant$ 25.247°), 3379 of which were unique, $R_{\rm int}$ = 0.0646, R_σ = 0.0714; completeness to θ of 25.242° was 99.8%. The refinement of 253 parameters with no restraints converged to R_1 = 0.0443, wR_2 = 0.0921 for 2367 reflections with $I > 2\sigma(I)$ and R_1 = 0.0783, wR_2 = = 0.1048 for all data with S = 1.004 and residual electron density, peak/hole 0.265/–0.339 eÅ^{-3}.

for d_2; the C(3), C(4) and C(10) atoms deviate to one side from this plane by 1.044(2), 0.942(1) and 0.808(1) Å for d_1 and by 1.014(3), 0.906(3) and 0.850(3) Å for d_2, respectively]. The six-membered heterocycles have a chair conformation; the N(1)–P(6)–O(7)–C(9) moiety is planar within 0.047(2) Å for d_1 and 0.045(2) Å for d_2; the corresponding deviations of the C(8) and C(10) atoms from this plane are 0.621(3) and –0.743(2) Å for d_1 as well as 0.619(2) and –0.814(1) Å for d_2. The difference in configuration of the diastereomeric molecules is in the position of the phenyl substituent at C(10) atom towards the seven-membered heterocycle, *viz.*, an equarorial position for d_1 and an axial position for d_2. The position of this substituent is opposite towards the six-membered heterocycle: it is axial for d_1 and equatorial for d_2. The carbonyl group [C(2)=O(2)] in both diastereomers is out of plane of the phenylene moiety: the dihedral angles between the N(1)–C(2)–O(2)–C(3) and C(2)–C(3)–C(4)–N(5) planar moieties are 55.0(2)° for d_1 and 57.5(1)° for d_2.

Thus, we have suggested an efficient approach to the synthesis of cage derivatives of aminophosphonic acids that involves the intramolecular reaction of the C=N exocyclic bond with the highly reactive P–O–C(O) moiety in 1,3,2-azaoxaphosphorin-4-ones. This approach can be extended to related cyclic systems where a phosphorus atom is bound to an exocyclic C=N bond through different possible spacers.

The spectral investigations were funded by the subsidy allocated to Kazan Federal University for the state assignment in the sphere of scientific activities (no. 4.5888.2017/8.9). The authors are grateful to the Assigned Spectral-Analytical Center of FRC Kazan Scientific Center of the Russian Academy of Sciences for technical assistance in research.

Crystal data for **4**(d_2). The structure was refined as a two-component twin. The twin law was found using the TwinRotMat routine of PLATON-200618[11] and the final model was refined against a combined set of diffraction indices. The minor domain with fractional contribution of 0.271(2) was rotated from the main one by reciprocal lattice two-fold twinning axis (1 0 0) and direct axis [5 0 1], the twin law was 1.000 0.000 0.335, 0.000 –1.000 0.000, 0.000 0.000 –1.000. $C_{22}H_{19}N_2O_3P$, M = = 390.36, monoclinic, $P2_1/c$ (no. 14), a = 9.2098(15), b = 19.385(3) and c = 10.5483(17) Å, β = 101.048(8)°, V = 1848.3(5) Å^3, Z = 4, Z' = 1, d_{calc} = = 1.403 g cm^{-3}, μ = 0.176 mm^{-1}, F(000) = 816, $T_{max/min}$ = 0.5455/0.5115; 54215 reflections were collected (2.101° ⩽ θ ⩽ 28.620°), 4704 of which were unique, R_σ = 0.0325; completeness to θ of 25.242° was 99.7%. The refinement of 254 parameters with no restraints converged to R_1 = = 0.0392, wR_2 = 0.0996 for 3958 reflections with $I > 2\sigma(I)$ and R_1 = 0.0505, wR_2 = 0.1063 for all data with S = 1.040 and residual electron density, peak/hole 0.302/–0.375 eÅ^{-3}.

CCDC 1863935 and 1863936 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* http://www.ccdc.cam.ac.uk.

Online Supplementary Materials

Supplementary data associated with this article can be found in the online version at doi: 10.1016/j.mencom.2019.03.010.

References

1 (*a*) F. Orsini, G. Sello and M. Sisti, *Curr. Med. Chem.*, 2010, **17**, 264; (*b*) Z. H. Kudzin, M. H. Kudzin, J. Drabowicz and C. V. Stevens, *Curr. Org. Chem.*, 2011, **15**, 2015; (*c*) K. V. Turcheniuk, V. P. Kukhar, G.-V. Röschenthaler, J. L. Aceña, V. A. Soloshonok and A. E. Sorochinsky, *RSC Adv.*, 2013, **3**, 6693; (*d*) G. S. Prasad and G. N. Rao, *J. Mod. Med. Chem.*, 2013, **1**, 49; (*e*) M. V. Makarov, E. S. Leonova, E. V. Matveeva, E. Y. Rybalkina, G.-V. Röschenthaler, T. V. Timofeeva and I. L. Odinets, *Phosphorus, Sulfur Silicon Relat. Elem.*, 2011, **186**, 908.

2 (*a*) L. Tušek-Božić, *Curr. Med. Chem.*, 2013, **20**, 2096; (*b*) K.-B. Huang, Z.-F. Chen, Y.-C. Liu, Z.-Q. Li, J.-H. Wei, M. Wang, G.-H. Zhang and H. Liang, *Eur. J. Med. Chem.*, 2013, **63**, 76.

3 (*a*) V. I. Galkin and R. A. Cherkasov, *Russ. Chem. Rev.*, 1998, **67**, 857 (*Usp. Khim.*, 1998, **67**, 940); (*b*) N. S. Zefirov and E. D. Matveeva, *ARKIVOC*, 2008, **i**, 1; (*c*) G. Keglevich and E. Bálint, *Molecules*, 2012, **17**, 12821; (*d*) T. E. Ali, *ARKIVOC*, 2014, **i**, 21; (*e*) J. P. Abell and H. Yamamoto, *J. Am. Chem. Soc.*, 2008, **130**, 10521; (*f*) A. A. Prishchenko, M. V. Livantsov, O. P. Novikova, L. I. Livantsova and E. R. Milaeva, *Heteroat. Chem.*, 2009, **20**, 70; (*g*) A. A. Prishchenko, M. V. Livantsov, O. P. Novikova and L. I. Livantsova, *Russ. J. Gen. Chem.*, 2010, **80**, 1889 (*Zh. Obshch. Khim.*, 2010, **80**, 1574).

4 (*a*) I. A. Litvinov, V. F. Mironov, A. T. Gubaidullin, I. V. Konovalova, L. M. Burnaeva, A. I. Konovalov, G. A. Ivkova and M. A. Kurykin, *Russ. J. Gen. Chem.*, 1999, **69**, 744 (*Zh. Obshch. Khim.*, 1999, **69**, 776); (*b*) V. F. Mironov, A. T. Gubaidullin, G. A. Ivkova, I. A. Litvinov, B. I. Buzykin, L. M. Burnaeva and I. V. Konovalova, *Russ. J. Gen. Chem.*, 2001, **71**, 420 (*Zh. Obshch. Khim.*, 2001, **71**, 457); (*c*) V. F. Mironov, A. T. Gubaidullin, L. M. Burnaeva, I. A. Litvinov, G. A. Ivkova, S. V. Romanov, T. A. Zyablikova, A. I. Konovalov and I. V. Konovalova, *Russ. J. Gen. Chem.*, 2004, **74**, 32 (*Zh. Obshch. Khim.*, 2004, **74**, 39).

5 M. N. Dimukhametov, G. A. Ivkova, V. F. Mironov, P. P. Onys'ko, Yu. V. Rassukanaya and R. Z. Musin, *Russ. J. Org. Chem.*, 2014, **50**, 605 (*Zh. Org. Khim.*, 2014, **50**, 616).

6 B. Kaboudin and K. Moradi, *Synthesis*, 2006, 2339.

7 (*a*) R. U. Pokalwar, R. V. Hangarge, B. R. Madje, M. N. Ware and M. S. Shingare, *Phosphorus, Sulfur Silicon Relat. Elem.*, 2008, **183**, 1461; (*b*) R. U. Pokalwar, S. A. Sadaphal, A. H. Kategaonkar, B. B. Shingate and M. S. Shingare, *Green Chem. Lett. Rev.*, 2010, **3**, 33; (*c*) A. H. Kategaonkar, R. U. Pokalwar, S. S. Sonar, V. U. Gawali, B. B. Shingate and M. S. Shingare, *Eur. J. Med. Chem.*, 2010, **45**, 1128; (*d*) D. R. Nagargoje, P. G. Mandhane, S. B. Bhagat, N. M. Chavan, P. V. Badadhe and C. H. Gill, *Pharma Chem.*, 2011, **3**, 1; (*e*) Z. Baccari, M. A. K. Sanhoury, B. Crousse and T. Barhoumi-Slimi, *Synth. Commun.*, 2018, **48**, 1199.

8 J. C. Anderson and H. A. Chapman, *Org. Biomol. Chem.*, 2007, **5**, 2413.

9 G. M. Sheldrick, *Acta Crystallogr., Sect. A: Found. Adv.*, 2015, **71**, 3.

10 G. M. Sheldrick, *Acta Crystallogr., Sect. C: Struct. Chem.*, 2015, **71**, 3.

11 A. L. Spek, *Acta Crystallogr., Sect. D: Biol. Crystallogr.*, 2009, **65**, 148.

Received: 3rd September 2018; Com. 18/5680