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Reaction of Secondary Phosphine Chalcogenides with Diallylamine

S. I. Verkhoturova, T. I. Kazantseva, S. N. Arbuzova, A. I. Albanov, N. K. Gusarova, and B. A. Trofimov

A.E. Favorskii Irkutsk Institute of Chemistry, Siberian Branch, Russian Academy of Sciences, ul. Favorskogo 1, Irkutsk, 664033 Russia
e-mail: boris_trofimov@irioch.irk.ru

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Abstract—Diphenyl- or bis(2-phenylethyl)phosphine sulfides and -phosphine selenides react with diallylamine under radical initiation (UV or AIBN) to afford the corresponding diadducts and tetrahydropyrrolylmethyl phosphine chalcogenides. The yield and the ratio of the products depend on the structure of the starting secondary phosphine chalcogenides.

Keywords: secondary phosphine chalcogenides, diallylamine, radical initiation, cyclization

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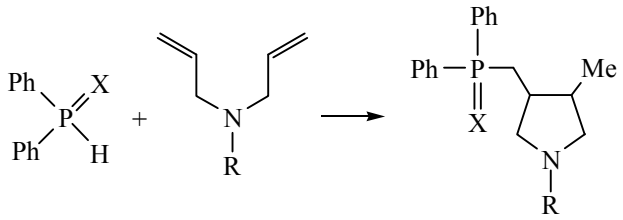
Addition of secondary phosphines and phosphine chalcogenides to polyalkenes is a convenient atom-economic approach to the synthesis of polyphosphines and polyphosphine chalcogenides including their functional derivatives. Reactions of this type have been successfully realized under radical conditions by the example of divinyl [1], diallyl [2, 3], trivinyl [4], tetravinyl [5] ethers, divinyl chalcogenides [6–9], as well as tris(4-vinylbenzyl)phosphine oxide [10]. As a result, promising polydentate ligands for metal complexes, including metallacrown ethers [1, 11–13] have been synthesized.

At the same time, there are no data in the literature on the reaction of diallylamine with secondary phosphine chalcogenides, although substituted diallylamines react with diphenylphosphine oxide (AIBN-initiation) [2] and diphenylphosphine sulfide (microwave activation) [3] to give cyclic adducts, phosphorus-containing pyrrolidines (Scheme 1).

Scheme 1.

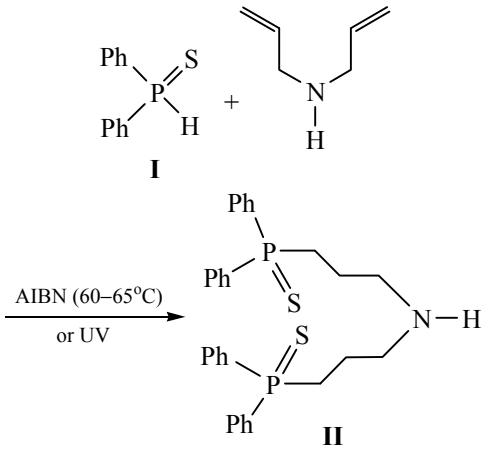


R = PhC(O), X = O [2]; R = *t*-BuOC(O), X = S [3].

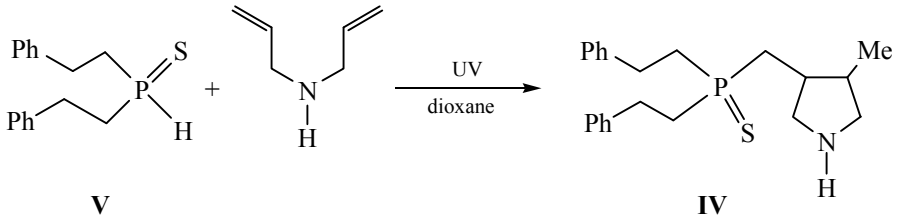
In the present work we have studied for the first time the radical addition of secondary phosphine sulfides and phosphine selenides to diallylamine in order to develop a general convenient atom-economic method of the synthesis of functional tertiary phosphine chalcogenides containing an amino group.

Diphenylphosphine sulfide (**I**) turned out to react with diallylamine (in the ratio 2 : 1) in benzene or dioxane at UV irradiation (200W Hg arc Lamp) or in the presence of AIBN (5 wt %, 60–65°C) in 2–2.5 h to give diadduct **II** as the main product (the isolated yield 52%). For the equimolar ratio of the reagents, compound **II** is also the main product (Scheme 2).

Scheme 2.

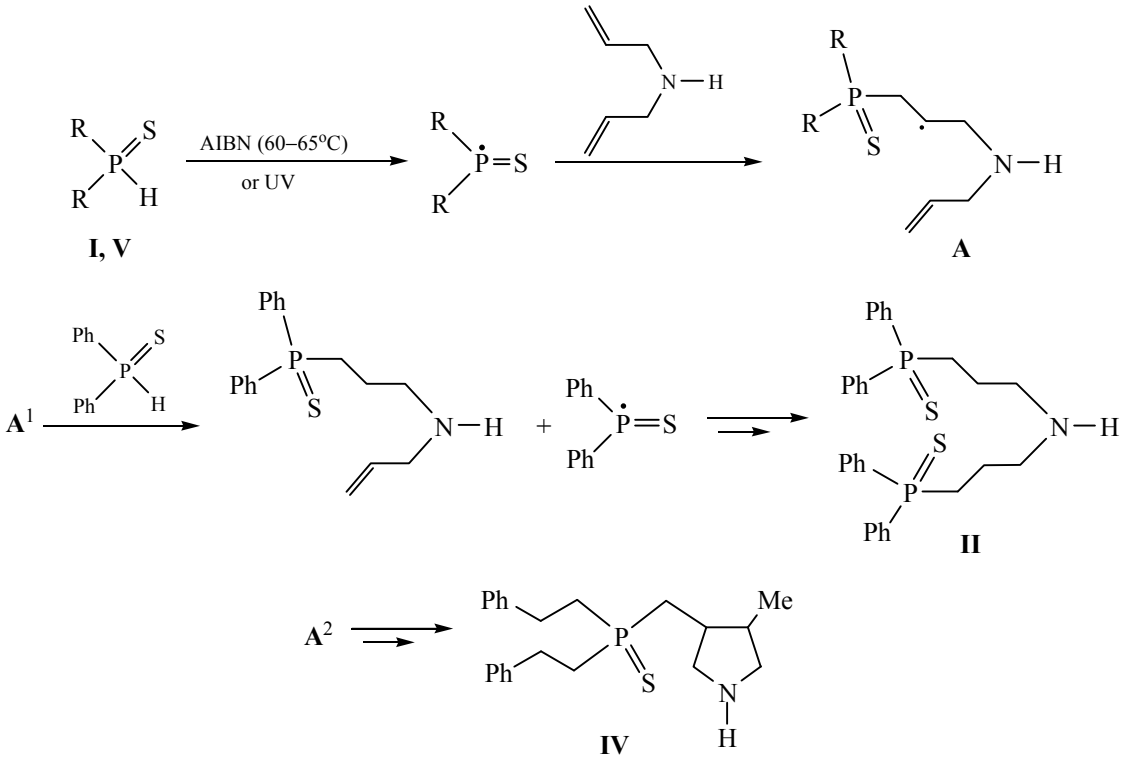


Scheme 3.



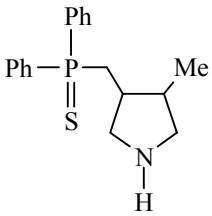
V **IV**

Scheme 4.



R = Ph (**A**[1]), $Ph(CH_2)_2$ (**A**[2]).

Besides, under these conditions, the formation of a small amount of side cyclic product, (4-methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenyl)phosphine sulfide (**III**) was detected by ^{1}H, ^{31}P NMR and chromatomass spectrometry:

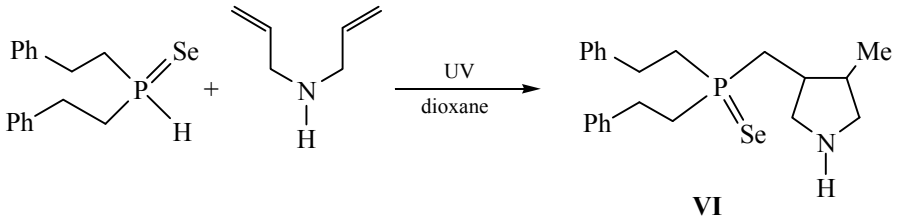


III

At the same time, a similar heterocycle, (4-methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenethyl)-phosphine sulfide (**IV**), is the major product of the radical addition (UV or AIBN-initiation, 60–65°C) of bis(2-phenylethyl)phosphine sulfide (**V**) to diallylamine in benzene or dioxane. Under optimal conditions (UV irradiation, dioxane, 7.5 h, the ratio of the reagents 1 : 1) compound (**IV**) was isolated in preparative yield of 45% (Scheme 3).

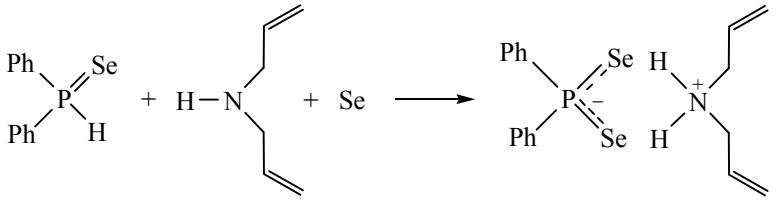
The difference in chemoselectivity of the studied reaction of diallylamine phosphorylation with phosphine sulfides **I, V** and the formation of tertiary phosphine sulfides **II–IV** can be rationalized as follows (Scheme 4). The P-centered radical generated from secondary phosphine sulfides adds to the double bond of the diallylamine molecule to form the C-centered radical (**A**), which can further react in two ways. In the case of diphenylphosphine sulfide **I**

Scheme 5.



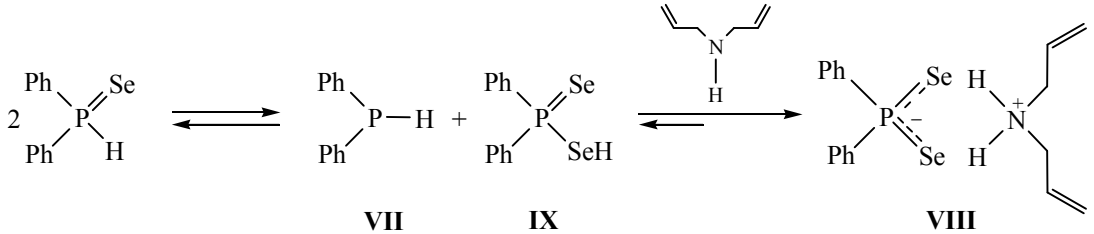
VI

Scheme 6.



VIII

Scheme 7.



VII **IX** **VIII**

radical ($\mathbf{A}^1$) readily abstracts hydrogen atom from the second molecule of phosphine sulfide to give a new P-centered radical. The latter is added to the double bond of the monoadduct to give diadduct **II**. As distinct of that, radical ($\mathbf{A}^2$) does not react with bis(2-phenylethyl)-phosphine sulfide (**V**) (where the P–H bond is, apparently, more strong as compared to that in the molecule of diphenylphosphine sulfide), but rather is added intramolecularly to the second double bond to form the cyclic product **IV**.

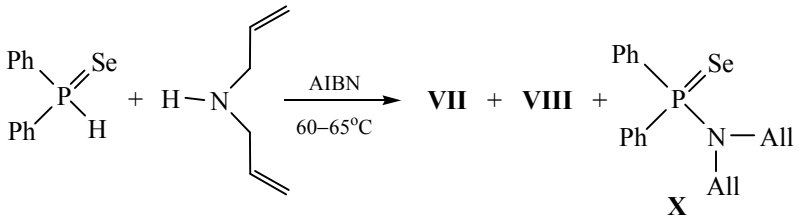
The reaction of secondary phosphine selenides with diallylamine under the conditions of radical initiation proceeds in a less selective manner. Thus, bis(2-phenylethyl)phosphine selenide reacts with diallylamine in the presence of AIBN (60–65°C, benzene) or under UV irradiation to form a mixture of organophosphorous compounds among which the main one (~60% according to the ^{31}P NMR spectra) is (4-methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenethyl)phosphine selenide (**VI**) (Scheme 5). Under optimal conditions (UV irradiation, dioxane, 4 h, the ratio of the reagents 1 : 1) phosphine selenide **VI** was isolated in preparative yield of 32%.

At the same time, the main products of the reaction of diphenylphosphine selenide with diallylamine under UV irradiation are diphenylphosphine **VII** and diallylammonium diphenylselenophosphinate **VIII**, whereas the expected acyclic and cyclic adducts are formed in small amounts. We failed to isolate compounds **VII, VIII** from the complex reaction mixture, but they were identified by ^{31}P NMR spectroscopy comparing with authentic samples. To this end, diselenophosphinate **VIII** was specially first synthesized by us from diphenylphosphine selenide, diallylamine, and elemental selenium by the known reaction [14] (Scheme 6).

The formation of compounds **VII, VIII** can be represented by Scheme 7 including the stage of reversible disproportionation of the secondary phosphine selenide to the corresponding secondary phosphine **VII** and diselenophosphinic acid **IX**. The latter reacts with diallylamine to give diselenophosphinate **VIII** thus shifting the equilibrium to the right.

A similar reaction of secondary phosphine selenides with amines at room temperature without initiator was described earlier [15].

Scheme 8.



In the case of chemical initiation (AIBN, 60–65°C, dioxane), diphenylphosphine selenide reacts with diallylamine to afford, along with compounds **VII, VIII**, also the amide of *N,N*-diallyl(diphenyl)seleno-phosphinic acid (**X**) (Scheme 8).

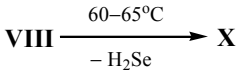
It turned out that this reaction takes place in the absence of initiator (60–65°C, dioxane). Under these conditions, amide **X** was isolated with the yield of 24%. The latter is formed, apparently, due to thermal decomposition of diselenophosphinate **VIII** according to Scheme 9 as suggested earlier [16].

Note that secondary phosphine oxides practically do not react with diallylamine under the developed conditions (UV initiation or in the presence of AIBN). This fact is in contradiction with the aforementioned literature data [2], but it is in accordance with the commonly accepted notions of a relatively low reactivity of secondary phosphine oxides in the reactions of radical addition to the double bond [3, 17–19].

It is important that the starting bis(2-phenylethyl)-phosphine sulfide and selenide are now available and can be readily prepared from elemental phosphorus, styrene, and elemental chalcogenides [20, 21].

Therefore, new fundamental data on the reactions of secondary phosphine chalcogenides with diallyl-amine were obtained. The course of the reaction depends both on the reaction conditions and on the structure of organic radical and the nature of the chalcogene in the molecule of the starting phosphine chalcogenide. Diorganylphosphine sulfides and bis(2-phenylethyl)phosphine selenide react with diallylamine under the conditions of radical initiation (AIBN, UV irradiation) via the diaddition route and/or mono-cycloaddition to afford the corresponding diadducts and tetrahydropyrrolylmethylphosphine chalcogenides. An original reaction of diphenylphosphine selenide with diallylamine was found leading to the mixture of organophosphorous compounds, the main products being diphenylphosphine, diallylammonium diphenyl-diselenophosphinate, and amide of *N,N*-diallyl(di-phenyl)seleno-phosphinic acid. Secondary phosphine oxides practically do not react with diallylamine under the studied conditions.

Scheme 9.



EXPERIMENTAL

^{1}H, ^{13}C, ^{31}P, and ^{77}Se spectra were registered on a Bruker DPX 400 spectrometer (400.13, 100.62, 161.98, and 76.31 MHz, respectively) in $CDCl_3$, internal reference HMDS (^{1}H, ^{13}C), Me_2Se (^{77}Se), external reference 85% H_3PO_4 (^{31}P). The signals in the ^{1}H, ^{13}C NMR spectra were assigned using 2D homo- and heteronuclear NMR techniques: COSY, HSQC. Mass spectra of electron impact (70 eV) were obtained on a GCMS-QP5050A SHIMADZU instrument (quadruple mass analyzer, the range of detected masses 34–450 Da, capillary column, SPB–5 phase).

***N*,*N*-Bis[3-(diphenylphosphorothioyl)propyl] amine (II).** The solution of diphenylphosphine sulfide **I** (0.093 g, 0.43 mmol) and diallylamine (0.021 g, 0.215 mmol) in 1.2 mL of benzene was placed in a quartz ampule flushed with argon and irradiated with UV light for 2.5 h. Benzene was removed under a reduced pressure, the residue was dried in a vacuum. The ^{31}P NMR spectrum of the obtained oily product contains signals at 47.3, 42.6, 41.51 ppm belonging to *N*,*N*-bis[3-(diphenylphosphorothioyl)propyl]amine **II**, *cis*- and *trans*-isomers of (4-methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenyl)phosphine sulfide (**III**), and non-identified signals at 57.3 and 60.7 ppm (the ratio of signals 25 : 8 : 2 : 1 : 1, respectively). The ^{1}H NMR spectrum, along with the signals characteristic of diadduct (**II**), shows the signals belonging to the *cis*- and *trans*-isomers of adduct **III**: 0.96 d (Me, $^{3}J_{HH}$ 7.0 Hz), 0.99 d (Me, $^{3}J_{HH}$ 6.7 Hz) in the ratio 4 : 1, respectively. In the mass spectrum two peaks of molecular ions with *m/z* 315 are present. The obtained oily product was dissolved in dioxane (2 mL) and passed through Al_2O_3

layer (6 mm) (eluent dioxane). Dioxane was removed under a reduced pressure, the residue was dried in a vacuum. Yield 0.06 g (52%), oily light-yellow compound. ^{1}H NMR spectrum, δ_H, ppm: 1.73 m (4H, $CH_2C\underline{H}_2CH_2$), 2.49 m (4H, CH_2P), 2.59 t (4H, CH_2N, $^3J_{HH}$ 6.7 Hz), 7.42 m (12H, *m*-Ph, *p*-Ph), 7.81 m (8H, *o*-Ph, $^3J_{HP}$ 13.0 Hz). ^{13}C NMR spectrum, δ_C, ppm: 22.25 ($CH_2\underline{C}H_2CH_2$), 29.99 d (CH_2P, $^1J_{CP}$ 57.1 Hz), 49.21 d (CH_2N, $^3J_{CP}$ 16.8 Hz), 128.43 d (C^m, $^3J_{CP}$ 12.8 Hz), 130.85 d (C^o, $^2J_{CP}$ 10.3 Hz), 131.25 (C^p), 132.53 d (C^{ipso}, $^1J_{CP}$ 80.2 Hz). ^{31}P NMR spectrum, δ_P, ppm: 43.7. Found, %: s 67.38; H 6.40; N 2.47; P 11.28; S 11.77. $C_{30}H_{33}NP_2S_2$. Calculated, %: C 67.52; H 6.23; N 2.62; P 11.61; S 12.02.

(4-Methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenethyl)phosphine sulfide (IV). The solution of bis(2-phenylethyl)phosphine sulfide (**V**) (0.114 g, 0.42 mmol) and diallylamine (0.041 g, 0.42 mmol) in 1 mL of dioxane was placed in a quartz ampule, flushed with argon and irradiated with UV light for 7.5 h. Dioxane was removed under a reduced pressure, the residue was dissolved in benzene (2 mL) and passed through Al_2O_3 layer (5 mm) (eluent benzene, then chloroform). From the chloroform solution the solvent was removed under a reduced pressure, the residue was dried in a vacuum. Yield 0.07 g (45%) (*cis*- and *trans*-isomers in the ratio of 5 : 1), oily light-yellow compound. ^{1}H NMR spectrum, δ_H, ppm (*cis*-isomer): 0.80 d (3H, Me, $^3J_{HH}$ 7.1 Hz), 1.65 d.d.d, 1.82 d.d.d (2H, $PC\underline{H}_2Pyr$, $^2J_{HH'}$ 15.0 Hz, $^2J_{HP}$ = $^3J_{HH}$ = 10.0 Hz, $^3J_{H'H}$ 4.0 Hz, $^2J_{H'P}$ 12.3 Hz), 2.04 m (4H, $PC\underline{H}_2$), 2.21 m (1H, CH^4), 2.41 m (1H, CH^3), 2.59 d.d, 3.11 d.d (2H, CH_2^5, $^2J_{HH'}$ 11.0 Hz, $^3J_{H^5H^4}$ 4.4 Hz, $^3J_{H^5'H^4'}$ 6.6 Hz), 2.71 d.d, 3.27 d.d (2H, CH_2^2, $^2J_{HH'}$ 10.7 Hz, $^3J_{H^2H^3}$ 7.2 Hz, $^3J_{H^2'H^3}$ 8.8 Hz), 2.83 m (4H, $C\underline{H}_2Ph$), 4.01 br.s (1H, NH), 7.10 m, 7.19 m (10H, Ph). ^{1}H NMR spectrum, δ_H, ppm (*trans*-isomer): 0.94 d (3H, Me, $^3J_{HH}$ 6.5 Hz), 1.65–1.82 m (1H, CH^4), the rest of signals of the *trans*-isomer are masked by the signals of the major *cis*-isomer. ^{13}C NMR spectrum, δ, ppm (*cis*-isomer): 14.11 (Me), 28.62 ($Ph\underline{C}H_2$), 32.74 d ($P\underline{C}H_2Pyr$, $^1J_{CP}$ 48.4 Hz), 33.39 d, 33.67 d ($PhCH_2\underline{C}H_2$, $^1J_{CP}$ 48.0 and 48.3 Hz respectively), 36.46 d (C^3, $^2J_{CP}$ 10.3 Hz), 37.13 d (C^4, $^3J_{CP}$ 3.2 Hz), 50.77 d (C^2, $^3J_{CP}$ 4.4 Hz), 52.83 (C^5), 126.58 (C^p), 128.21, 128.25, 128.28, 128.71 (C^o, C^m), 140.41 d, 140.43 d (C^{ipso}, $^3J_{CP}$ 13.3 and 13.5 Hz respectively). ^{13}C NMR spectrum, δ, ppm (*trans*-isomer): 16.46 (Me), 28.54 d ($Ph\underline{C}H_2$, $^2J_{CP}$ 2.7 Hz), 33.35 d ($P\underline{C}H_2Pyr$, $^1J_{CP}$ 48.1 Hz), 33.70 d, 34.24 d ($PhCH_2\underline{C}H_2$, $^1J_{CP}$ 49.7 and 47.7 Hz respectively), 41.43 d (C^3, $^2J_{CP}$ 12.5 Hz), 41.63 d (C^4, $^3J_{CP}$ 3.7 Hz), 49.85 d (C^2, $^3J_{CP}$ 15.6 Hz), 52.70 (C^5), 126.51 (C^p), 128.24, 128.34, 128.37, 128.67 (C^o, C^m), 140.56 d, 142.16 d (C^{ipso}, $^3J_{CP}$ 13.9 and 16.9 Hz respectively). ^{31}P NMR spectrum, δ_P, ppm: 49.4 (*cis*-isomer), 48.3 (*trans*-isomer). Found, %: C 70.88; H 7.98; N 3.59; P 8.12; S 8.45. $C_{22}H_{30}NPS$. Calculated, %: s 71.12; H 8.14; N 3.77; P 8.34; S 8.63.

(4-Methyltetrahydro-1*H*-pyrrol-3-yl)methyl(diphenethyl)phosphine selenide (VI). The solution of bis(2-phenylethyl)phosphine selenide (**V**) (0.049 g, 0.15 mmol) and diallylamine (0.014 g, 0.15 mmol) in 1 mL of dioxane was placed in a quartz ampule, flushed with argon and irradiated with UV light for 4 h. Dioxane was removed under reduced pressure, the residue was dissolved in chloroform (2 mL) and passed through Al_2O_3 layer (5 mm) (eluent chloroform, 20 mL). Chloroform was removed under a reduced pressure, the residue was washed with diethyl ether (3 × 2 mL), dried in a vacuum. Yield 0.02 g (32%, purity 95 %), (*cis*- and *trans*-isomers in the ratio of 4 : 1, oily light-yellow compound. ^{1}H NMR spectrum, δ_H, ppm (*cis*-isomer): 0.94 d (3H, Me, $^3J_{HH}$ 7.1 Hz), 1.93 m (2H, $PC\underline{H}_2Pyr$), 2.24 m (4H, $PC\underline{H}_2$), 2.44 m (1H, CH^4), 2.32 m, 2.96 m (2H, CH_2^5), 2.51 m, 3.04 m (2H, CH_2^2), 2.59 m, 3.04 m (1H, CH_2^3), 2.96 m (4H, $C\underline{H}_2Ph$), 7.20 m, 7.25 m (10H, Ph). ^{1}H NMR spectrum, δ, ppm (*trans*-isomer): 1.02 d (3H, Me, $^3J_{HH}$ 6.6 Hz), the rest of signals of the *trans*-isomer are masked by the signals of the major *cis*-isomer. ^{13}C NMR spectrum, δ, ppm (*cis*-isomer): 13.41 (Me), 29.39 d ($Ph\underline{C}H_2$, $^2J_{CP}$ 3.0 Hz), 33.21 d, 33.28 d ($PhCH_2\underline{C}H_2$, $^1J_{CP}$ 41.8 and 41.4 Hz respectively), 35.92 d (C^3, $^2J_{CP}$ 9.9 Hz), 37.06 d (C^4, $^3J_{CP}$ 2.2 Hz), 40.28 d ($P\underline{C}H_2Pyr$, $^1J_{CP}$ 57.8 Hz), 48.26 d (C^2, $^3J_{CP}$ 4.3 Hz), 50.37 (C^5), 126.74 (C^p), 128.30, 128.40, 128.50, 128.81 (C^o, C^m), 141.57 d, 141.74 d (C^{ipso}, $^3J_{CP}$ 17.3 and 16.1 Hz respectively). ^{31}P NMR spectrum, δ_P, ppm: 37.7 (+ satellites, $^1J_{PSe}$ 706.5 Hz) (*cis*-isomer), 36.3 (*trans*-isomer). ^{77}Se NMR spectrum, δ_{Se}, ppm (*cis*-isomer): –75.0 d ($^1J_{SeP}$ 706.5 Hz).

Diallylammonium diphenyldiselenophosphinate (VIII). To the solution of diphenylphosphine selenide (0.117 g, 0.44 mmol) and diallylamine (0.064 g, 0.66 mmol) in 3 mL of dioxane amorphous selenium was added (0.035 g, 0.44 mmol). The mixture was stirred at 60–65°C for 3.5 h, filtered, dioxane removed under a reduced pressure, the residue was washed with diethyl ether (3 × 2 mL), dried in a vacuum. Yield 0.13 g (67 %), powder of light pink color, mp. 89–92°C. ^{1}H NMR spectrum, δ_H, ppm: 3.58 d (4H, CH_2N, $^3J_{HH}$ 6.9 Hz), 5.28 br.d ($2H_{trans}$, $=CH_2$, $^3J_{HH}$ 17.1 Hz), 5.29 br.d ($2H_{cis}$, $=CH_2$, $^3J_{HH}$ 10.2 Hz), 5.81 d.d.t (2H, =CH,

$^3J_{HH}$ 10.2 Hz, $^3J_{HH}$ 17.1 Hz, $^3J_{HH}$ 6.9 Hz), 7.23 m (6H, *m*-Ph, *p*-Ph), 8.10 m (4H, *o*-Ph). ^{13}C NMR spectrum, δ_C, ppm: 48.25 (CH_2N), 123.95 (=CH_2), 128.29 d (C^m, $^3J_{CP}$ 12.1 Hz), 129.03 (=CH), 130.49 d (C^p, $^4J_{CP}$ 1.7 Hz), 131.88 d (C^o, $^2J_{CP}$ 12.1 Hz), 140.76 d (C^{ipso}, $^1J_{CP}$ 78.0 Hz). ^{31}P NMR spectrum, δ_P, ppm: 22.7 (+ satellites, $^1J_{PSe}$ 586 Hz). Found, %: s 48.72; H 4.98; N 3.06; P 6.76; Se 35.52. $C_{18}H_{22}NPSe_2$. Calculated, %: C 48.99; H 5.03; N 3.17; P 7.02; Se 35.79.

Amide of *N,N*-diallyl(diphenyl)selenophosphinic acid (X). The solution of diphenylphosphine selenide (0.093 g, 0.35 mmol) and diallylamine (0.034 g, 0.35 mmol) in 2 mL of dioxane was flushed with argon and stirred at 60–65°C for 3 h. The ^{31}P NMR spectrum of the reaction mixture contains the signals at –40.0 ($^1J_{PH}$ 210 Hz), 22.4 (satellites, $^1J_{PSe}$ 586 Hz) and 69.4 ppm (satellites: $^1J_{PSe}$ 754.8 Hz) from diphenylphosphine **VII**, diselenophosphinate **VIII**, and amide **X**, and a non-identified signal at 53.0 ppm (the ratio of signals 1 : 2 : 2 : 1 respectively). Dioxane was removed under a reduced pressure, the residue was dissolved in benzene, the solution was passed through Al_2O_3 layer (1 cm) (eluent benzene). Benzene was removed under a reduced pressure, the residue was dried in a vacuum. Yield 0.03 g (24%), light-yellow waxy product. ^{1}H NMR spectrum, δ_H, ppm: 3.55 d.d (4H, CH_2N, $^3J_{HH}$ 6.5 Hz, $^3J_{HP}$ 11.7 Hz), 5.06 d.d.t (2H$_{trans}$, =CH_2, $^3J_{HH}$ 17.0 Hz, $^2J_{HH}$ 1.3 Hz, $^4J_{HH}$ 1.2 Hz), 5.12 br.d (2H$_{cis}$, =CH_2, $^3J_{HH}$ = 10.2 Hz), 5.83 d.d.t (2H, =CH, $^3J_{HH}$ 17.0 Hz, $^3J_{HH}$ 10.2 Hz, $^3J_{HH}$ 6.5 Hz), 7.43 m (6H, *m*-Ph, *p*-Ph), 8.00 m (4H, *o*-Ph). ^{13}C NMR spectrum, δ_C, ppm: 49.74 (CH_2N), 118.58 (=CH_2), 128.41 d (C^m, $^3J_{CP}$ 13.4 Hz), 131.82 d (=CH, $^3J_{CP}$ 2.6 Hz), 132.52 d (C^o, $^2J_{CP}$ 11.2 Hz), 132.86 d (C^{ipso}, $^1J_{CP}$ 114.7 Hz), 133.97 d (C^p, $^4J_{CP}$ 6.0 Hz). ^{31}P NMR spectrum, δ_P, ppm: 69.3 (+ satellites, $^1J_{PSe}$ 754.8 Hz). ^{77}Se NMR spectrum, δ_{Se}, ppm: –267.5 d ($^1J_{SeP}$ 754.8 Hz). Found, %: s 59.86; H 5.42; N 3.67; P 8.43; Se 21.78. $C_{18}H_{20}NPSe$. Calculated, %: C 60.00; H 5.60; N 3.89; P 8.60; Se 21.92.

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REFERENCES

1. Oparina, L.A., Gusarova, N.K., Vysotskaya, O.V., Kolyvanov, N.A., Artem'ev, A.V., and Trofimov, B.A., *Synthesis*, 2012, no. 44, p. 2938.
2. Jessop, C.M., Parsons, A.F., Routledge, A., and Irvine, D.J., *Tetrahedron Lett*., 2003. vol. 44, p. 479.
3. Jessop, C.M., Parsons, A.F., Routledge, A., and Irvine, D.J., *Eur. J. Org. Chem*., 2006, no. 6, p. 1547.
4. Oparina, L.A., Gusarova, N.K., Vysotskaya, O.V., Artem'ev, A.V., Kolyvanov, N.A., and Trofimov, B.A., *Synthesis*, 2014, no. 46, p. 653.
5. Trofimov, B.A., Malysheva, S.F., Belogorlova, N.A., Kuimov, V.A., Albanov, A.I., and Gusarova, N.K., *Eur. J. Org. Chem.*, 2009, p. 3427.
6. Trofimov, B.A., Gusarova, N.K., Malysheva, S.F., Sukhov, B.G., Belogorlova, N.A., Kuimov, V.A., and Al'pert, M.L., *Sulfur Lett*., 2003, vol. 26, no. 2, p. 63.
7. Gusarova, N.K., Volkov, P.A., Ivanova, N.I., Chernysheva, N.A., Yas'ko, S.V., Albanov, A.I., and Trofimov, B.A., *Russ. J. Gen. Chem*., 2010, vol. 80, no. 8, p. 1602.
8. Gusarova, N.K., Chernysheva, N.A., Yas'ko, S.V., Klyba, L.V., and Trofimov, B.A., *Russ. J. Gen. Chem*., 2011, vol. 81, no. 12, p. 2506.
9. Gusarova, N.K., Chernysheva, N.A., Klyba, L.V., Shagun, V.A., Yas'ko, S.V., Smirnov, V.I., and Trofimov, B.A., *J. Organomet. Chem*., 2013, vols. 745–746, p. 126.
10. Gusarova, N.K., Kuimov, V.A., Malysheva, S.F., Belogorlova, N.A., Albanov, A.I., and Trofimov, B.A., *Tetrahedron*, 2012, vol. 68, p. 9218.
11. Smith, D.C., Lake, C.H., and Gray, G.M., *Dalton Trans*., 2003, p. 2950.
12. Owens, S.B., Smith, D.C., Lake, C.H., and Gray, G.M., *Eur. J. Inorg. Chem*., 2008, p. 4710.
13. Owens, S.B. and Gray, G.M., *Organometallics*, 2008, vol. 27, p. 4282.
14. Trofimov, B.A., Artem'ev, A.V., Gusarova, N.K., Malysheva, S.F., Fedorov, S.V., Kazheva, O.N., Alexandrov, G.G., and Dyachenko, O.A., *Synthesis*, 2009, no. 19, p. 3332.
15. Trofimov, B.A., Artem'ev, A.V., Malysheva, S.F., and Gusarova, N.K., *Dokl. Chem*., 2009, vol. 428, no. 1, p. 225.
16. Gusarova, N.K., Verkhoturova, S.I., Kazantseva, T.I., Arbuzova, S.N., Albanov, A.I., and Trofimov, B.A., *Mendeleev Commun*., 2013, vol. 23, no. 5, p. 253.
17. Trofimov, B.A., Gusarova, N.K., Chernysheva, N.A., Yas'ko, S.V., Kazantseva, T.I., and Ushakov, I.A., *Synthesis*, 2008, no. 17, p. 2743.
18. Gusarova, N.K., Kuimov, V.A., Malysheva, S.F., Belogorlova, N.A, Albanov, A.I., and Trofimov, B.A., *Tetrahedron*, 2012, vol. 68, p. 9218.
19. Gusarova, N.K., Verkhoturova, S.I., Kazantseva, T.I., Arbuzova, S.N., Albanov, A.I., Tatarinova, A.A., and Trofimov, B.A., *Russ. J. Gen. Chem*., 2013, vol. 83, no. 10, p. 1895.
20. Trofimov, B.A. and Gusarova, N.K., *Mendeleev Commun*., 2009, vol. 19, no. 6, p. 295.
21. Gusarova, N.K., Arbuzova, S.N., and Trofimov, B.A., *Pure Appl. Chem*., 2012, vol. 84, p. 439.