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Stereoselective Reactions of Optically Active Derivatives of α-Methylbenzylaminophosphine

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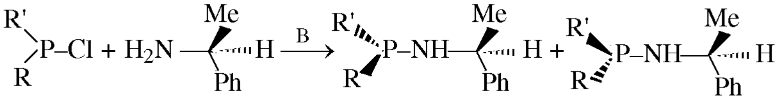
Abstract—A number of *N*-(α-methylbenzyl) phosphorus amides were synthesized, and their stereochemical properties were studied. Reactions of achiral chlorophosphines with optically active α-methylbenzylamine are accompanied by asymmetric induction at the phosphorus atom to give optically active diastereoisomers of *N*-(α-methylbenzyl)aminophosphines, which were isolated as the corresponding borane complexes with 100% optical purity. Stereochemically pure (*R*,*S*)-aminophosphines were obtained by decomposition of these complexes via treatment with diethylamine. Their oxidation, sulfurization, and alkylation with methyl iodide afforded optically active aminophosphine derivatives. Hydrolysis of (*R*,*S*)-aminophosphines gave optically active *tert*-butylphenylphosphine oxide and phosphonic acid amides. (*R*,*S*)- and (*S*,*S*)-Diastereoisomers of *N*-(α-methylbenzyl)phosphinic amides were separated by crystallization and flash chromatography, and their absolute configuration was established. Also, derivatives of bis- and tris(α-methylbenzylamino)phosphines were synthesized.

α-Methylbenzylamine is one of the most important reagents for stereochemical studies in organic chemistry. Numerous optically active derivatives of α-methylbenzylamine were synthesized and used in various theoretical and applied studies [1–3]. However, optically active organophosphorus derivatives of α-methylbenzylamine were studied very poorly, while those containing tervalent phosphorus were unknown at all prior to our works [3, 4]. Optically acitive phosphorus(III) derivatives of α-methylbenzylamine attract interest as starting compounds for the synthesis of chiral organophosphorus compounds which may be important as chiral ligands, catalysts, and biologically active substances. The chemistry of optically active α-methylbenzylaminophosphine derivatives is also interesting, as follows from the transformations and properties of these compounds, described in this article. We have synthesized compounds containing different numbers of amino groups: *N*-mono-, *N*,*N*'-bis-, and *N*,*N'*,*N*"-tris(α-methylbenzyl)phosphorus acid amides, and examined their properties.

Monosubstituted *N*-(α-methylbenzyl)phosphinous amides were synthesized by reaction of the corresponding phosphorus chlorides with 2 equiv of α-methylbenzylamine or with a mixture of α-methylbenzylamine and triethylamine. The reaction of phosphinous acid chlorides **Ia**–**Ic** with a mixture of (–)-(*R*)-methylbenzylamine and triethylamine readily occurs in diethyl ether, benzene, or toluene, yielding N-substituted phosphinous amides **IIa**–**IIc**. The reaction is relatively slow at room temperature, but *N*-(α-methylbenzyl)phosphinous amides **IIa**–**IIc** are formed in very good yields in 8–12 h.



Ia–**Ic** **IIa**–**IIc**

I, II, R = *i*-Bu, R' = *t*-Bu (**a**); R = Ph, R' = *t*-Bu (**b**); R = Ph, R' = 2,4,6-$(CH_3)_3C_6H_2$ (**c**); B is a base.

N-(α-Methylbenzyl)phosphinous amides **IIa** and **IIb** are stable colorless liquids which can be distilled under reduced pressure. Compounds **II** can be stored for a long time with protection from atmospheric moisture and oxygen. However, they are readily oxidized with atmospheric oxygen and readily undergo various transformations, as will be shown below. Diastereoisomers of compounds **IIa**–**IIc** were

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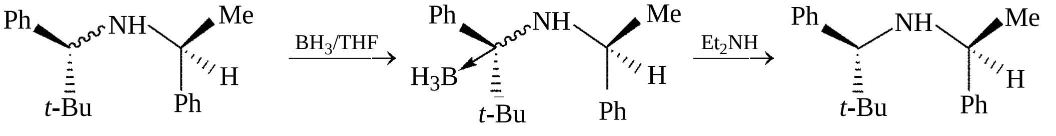
Stereoselectivity of formation of α-methylbenzylaminophosphines R(R')PNHCH(Me)Ph (**IIa**–**IIc**)

Comp. no.	R	R'	Reaction conditions (20°C)		Diastereoisomer ratio[a]
			solvent	base	
IIa	*t*-Bu	*i*-Bu	Diethyl ether	Triethylamine	36:64
IIb	*t*-Bu	Ph	"	"	10:90
IIb[b]	*t*-Bu	Ph	Benzene	"	18:82
IIb	*t*-Bu	Ph	"	α-Methylbenzylamine	17.5:82.5
IIb	*t*-Bu	Ph	Toluene	Diazabicyclooctane	25:75
IIb	*t*-Bu	Ph	"	Diazabicycloundecene	42:58
IIb	*t*-Bu	Ph	Diethyl ether	Triethylamine	12:88
IIb	*t*-Bu	Ph	Hexane	"	20:80
IIb	*t*-Bu	Ph	THF	"	38:62
IIc	Ph	2,4,6-$(CH_3)_3C_6H_2$	Benzene	"	75:25

[a] Determined by ^{31}P NMR spectroscopy as average value from 2–3 measurements. [b] At 70°C.

identified by NMR spectroscopy and high-performance liquid chromatography (HPLC). The $^{31}P–\{^1H\}$ NMR spectra were the most informative: the diastereoisomers give rise to sharp peaks at a considerable distance from each other. The diastereoisomer ratio depends on the reaction conditions (see table), including the nature of the organic base and solvent and temperature. (*R*)- and (*S*)-α-Methylbenzylamines give rise, respectively, to (*R*,*S*)/(*S*,*S*)- and (*S*,*R*)/(*R*,*R*)-diastereoisomers of aminophosphines **II** at a ratio of 10:1. The mixtures of diastereoisomers were separated into stereochemically pure (*R*,*S*) and (*R*,*R*) compounds through the corresponding borane complexes. For example, the reaction of α-methylbenzylaminophosphine **IIa** with the borane–tetrahydrofuran complex quantitatively afforded crystalline complexes **III** which can be isolated with a 100% stereochemical purity by recrystallization from hexane.

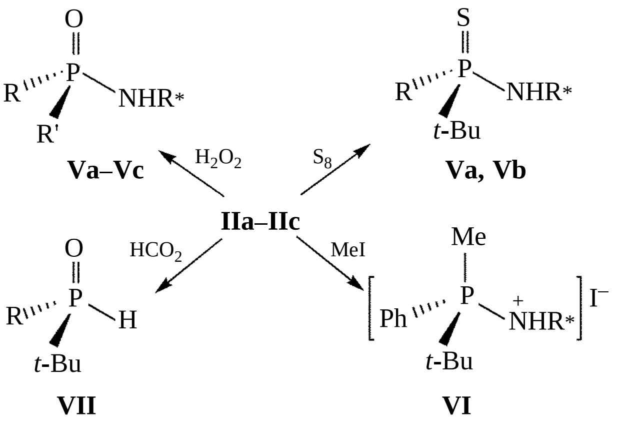


(*R*,*S*)-**IIb** + (*S*,*S*)-**IIb** (*R*,*S*)-**IIIb** (*R*,*S*)-**IIb**, 100% *de*

Treatment of a mixture of (*R*,*S*) and (*S*,*S*) diastereoisomers of **IIb** with the BH_3–THF complex gave the only diastereoisomer of phosphine–borane complex **III**. Its structure and stereochemical purity were confirmed by the ^{1}H, ^{13}C, and ^{31}P NMR spectra. The chemical shift of the phosphorus atom in **III** is equal to +70 ppm; its signal appears as a broadened doublet due to coupling with ^{11}B. The ^{1}H and ^{13}C NMR spectra of **III** contain signals from all hydrogen and carbon atoms present in the molecule. There were no signals indicating the presence of other diastereoisomers.

The phosphine–borane complex was decomposed by treatment with excess diethylamine. This reaction is stereospecific, and configuration of the phosphorus atom is retained [5–8]. The process is fairly slow: it is completed by heating a solution of the complex in diethylamine for 16 h at 50°C. The resulting diastereoisomerically pure product was identical to the initial aminophosphine (a mixture of diastereoisomers) according to the ^{31}P NMR spectrum of a mixture of the two samples. Optically pure *tert*-butyl(α-methylbenzylamino)phenylphosphine (**IIb**) is a colorless liquid which can be distilled under reduced pressure without appreciable decomposition.

N-Phosphorylated amines **IIa**–**IIc** are convenient initial compounds for the preparation of stereochemically pure chiral reagents. Oxidation of aminophosphines **IIa** and **IIb** with hydrogen peroxide in dioxane occurs in a stereospecific fashion and gives aminophosphine oxides **IVa**–**IVc** in very good yields.



R* = (*S*)-CH(Me)Ph; R = *i*-Bu, R' = *t*-Bu (**a**); R = Ph, R' = *t*-Bu (**b**); R = Ph, R' = 2,4,6-$(CH_3)_3C_6H_2$ (**c**).

The (*S*,*S*)- and (*R*,*S*)-diastereoisomers of aminophosphine oxide **IVb** were identified by the ^{31}P NMR spectra. Their ratio and purity were checked by HPLC. The major (*R*,*S*)-diastereoisomer was characterized by greater retention time, and the minor (*S*,*S*)-isomer left the column first. No appreciable difference in the ratios of diastereoisomers, determined from the ^{31}P NMR and HPLC data, was observed. Diastereoisomeric products **IV** were separated by flash chromatography using 50-cm columns packed with silica gel (Merck) and a 92 : 8 mixture of hexane with isopropyl alcohol as eluent. Fractions containing different diastereoisomers were analyzed by HPLC. We succeeded in separating the diastereoisomers completely and isolating them in the pure state. The subsequent recrystallization gave compounds **IV** with a diastereoisomeric purity of ~100% (according to the ^{1}H and ^{31}P NMR data). Their NMR spectra contained singlets from the *tert*-butyl groups (without any doubling). The ^{1}H NMR spectrum of *tert*-butyl(isobutyl)-α-methylbenzylaminophosphine oxide (**IVa**) revealed magnetic nonequivalence of some protons, specifically of the methyl protons in the isobutyl group.

By sulfurization of compounds **IIa** and **IIb** we obtained aminophosphine sulfides **Va** and **Vb** as mixtures of two diastereoisomers which are clearly distinguished by HPLC and NMR. The major diastereoisomer of **Vb** was isolated and purified by recrystallization from hexane. The product (colorless needles) had a diastereoisomeric purity of 100%. The minor stereoisomer of **Vb** was isolated as a colorless viscous liquid containing ~20% of the major isomer which could not be separated by crystallization and column chromatography. *N*-Phosphorylated amine **IIa** is readily alkylated with methyl iodide to give phosphonium salt **VI**.

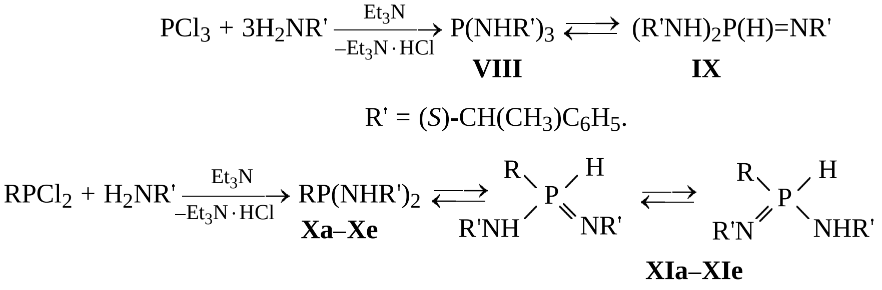
The hydrolysis of (R_P,S)-*tert*-butyl(α-methylbenzylamino)phenylphosphine (**IIb**) in aqueous dioxane at 80°C was complete in 12 h; the reaction afforded optically active (α)-(*S*)-*tert*-butyl(α-methylbenzylamino)phenylphosphine oxide (**VII**). The acidolysis of phosphinous amide **IIb** with formic acid in toluene at 0°C took 15–30 min and afforded the same optically active product **VII**. Unlike tervalent phosphorus compounds **II**, phosphorus(V) derivatives **IV** and **V** are very stable to hydrolysis; they do not change on heating for 48 h in boiling aqueous dioxane containing 0.1 N sulfuric acid [9]. This reaction provides a convenient procedure for the preparation of (*S*)- and (*R*)-enantiomers of *tert*-butyl(phenyl)phosphine oxide from accessible *tert*-butylchlorophosphine and (*S*)- and (*R*)-enantiomers of α-methylbenzylamine. (*S*)- and (*R*)-Enantiomers of *tert*-butyl(phenyl)phosphine oxide are relatively difficultly accessible compounds. The known methods for their synthesis include a number of steps, and they cannot be regarded as preparative [10–12]. The specific optical rotation and other physical parameters of product **VII** coincided with the data reported in [10, 11].

The absolute configurations of the products were established by X-ray analysis, chemical transformations, and chemical correlation. The absolute configuration of the (*S*,*S*)-diastereoisomer of aminophosphine oxide **IV** was determined on the basis of the X-ray diffraction data. The results allowed us to assign (R_P)-configuration to initial aminophosphine **II** and (*S*)-configuration to the sulfurization, alkylation, and hydrolysis products (compounds **V**–**VII**). These reactions are stereospecific, and they follow S_N2 mechanism with inversion of configuration at the phosphorus atom [13, 14]. The (*S*)-configuration of hydrolysis product **VII** was also confirmed by the negative optical rotation value.

The amino group in compound (S,S_P)-(+)-(**IVc**) is replaced by methoxy group on heating for 5 h in boiling methanol containing sulfuric acid. As a result, previously reported methyl (α)-(*R*)-mesityl(phenyl)phosphinate [9] was obtained with an ee (enantiomeric excess) value of 75%. In keeping with the negative optical rotation value, the phosphorus configuration in the initial amide should be S_P, for S_N2 substitution is accompanied by inversion of configuration [14].

Interesting chemical properties are exhibited by chiral phosphorus(III) bis- and tris(alkylamides) **VIII** and **X** which exist in equilibrium with tautomeric iminophosphoranes **IX** and **XI**, as we reported previously [15, 16]. Phosphorous tris(α-methylbenzylamide) (**VIII**) was synthesized by reaction of 3 equiv of α-methylbenzylamine with phosphorus(III) chloride in the presence of triethylamine in toluene. Alkyl- and arylphosphonous bis(α-methylbenzylamides)

Xa–**Xe** were prepared by treatment of the corresponding alkyl- and aryldichlorophosphines with 2 equiv of α-methylbenzylamine in toluene in the presence of excess triethylamine. The procedures for the synthesis of phosphorus(III) amides **VIII** and **X** and their spectral parameters were reported by us previously [4].



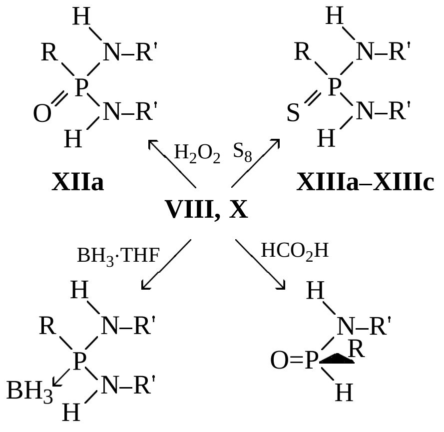
VIII **IX**

R' = (*S*)-CH(CH$_3$)C$_6$H$_5$.

Xa–**Xe** **XIa**–**XIe**

R = Ph (**a**), 4-C$_6$H$_4$F (**b**), 4-Me$_2$NC$_6$H$_4$ (**c**), Me (**d**), *t*-Bu (**e**); R' = (*S*)-CH(CH$_3$)C$_6$H$_5$.

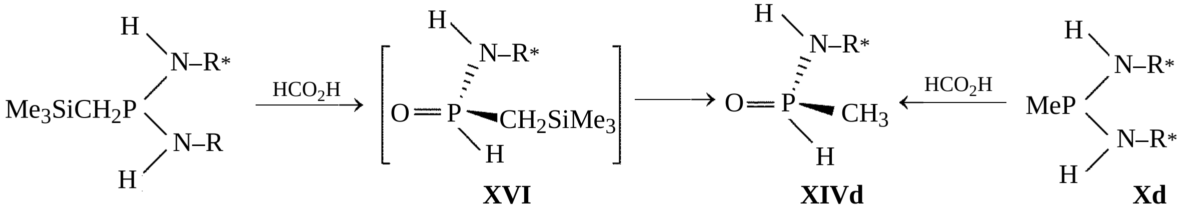
In this work we examined some chemical transformations of compounds **VIII** and **X**. Insofar as these compounds are unstable, they were brought into further reactions without isolation or the reaction mixture was filtered and evaporated under reduced pressure. The residue obtained after evaporation was spectroscopically pure compound **VIII** or **X** which was then treated with appropriate reagent, and the products were characterized as stable derivatives. Phosphorous tris(α-methylbenzylamide) (**VIII**) readily reacts with borane in THF to give stable borane complex **XVf**. Phenylphosphonous bis(α-methylbenzylamide) (**Xa**) was oxidized with hydrogen peroxide to obtain the corresponding phosphine oxide **XIIa** in quantitative yield. Compounds **Xa**–**Xc** took up elemental sulfur in toluene or benzene solution with formation of crystalline phosphine sulfides **XIIIa**–**XIIIc**. The reactions were carried out with equimolar amounts of the reactants, for the use of excess sulfur strongly impairs the purity of the products. Bisamides **X** readily undergo acidolysis and hydrolysis, yielding phosphinic amides **XIVd** and **XIVe**. These reactions smoothly occurred with formic acid in toluene.



XIIa **XIIIa**–**XIIIc** **VIII, X** **XVf** **XIVd, XIVe**

R = Ph (**a**), 4-C$_6$H$_4$F (**b**), 4-Me$_2$NC$_6$H$_4$ (**c**), Me (**d**), *t*-Bu (**e**), (*S*)-NHCH(CH$_3$)C$_6$H$_5$ (**f**); R' = (*S*)-CH(CH$_3$)C$_6$H$_5$.

The reaction of trimethylsilylmethylphosphonous bis(α-methylbenzylamide) with formic acid was accompanied by desilylation of intermediate monoamide **XVI** to give methylphosphinic amide **XIVd** [17]. The same product was obtained by acidolysis of phosphorous diamide **Xd**.



XVI **XIVd** **Xd**

R* = (*S*)-CH(CH$_3$)C$_6$H$_5$.

The high stereoselectivity of this transformation is worth noting. *N*-(α-Methylbenzyl)methylphosphinic amide (**XIVd**) was isolated as a single diastereoisomer (according to the NMR spectra). Phosphinic amides **XIVd** and **XIVe** are stable substances which can be purified by vacuum distillation or crystallization. Their ^{1}H and ^{31}P NMR spectra contain a doublet with a direct P–H coupling constant of 490–500 Hz.

EXPERIMENTAL

The melting points were not corrected. The NMR spectra were recorded on Varian VXR-300 (300 MHz for ^{1}H and 126.16 MHz for ^{31}P) and Jeol (90 MHz) spectrometers. The chemical shifts are given in the δ scale (ppm) relative to tetramethylsilane (internal reference, ^{1}H) and 85% H_3PO_4 (external reference, ^{31}P). HPLC analysis was performed on Milikhrom-1A (Russia) and LKB (Sweden) instruments under the following conditions: Ultrapack TSK-ODS-120-T (5 μm), column 250 × 4.6 mm, eluent 65–75% aqueous methanol; Silasorb DEA, column 120 × 2 mm, hexane–2-propanol, 95 : 5; Silasorb C-18, column 120 × 2 mm, 50% aqueous acetonitrile; UV detector, λ 260 nm. Silicagel L 100/160 μm (Chemapol, Czechia) was used for column chromatography. All operations were carried out under argon. The solvents were preliminarily distilled in an inert atmosphere from P_2O_5 (diethyl ether, hexane, heptane, benzene, CCl_4), metallic sodium (methanol, triethylamine), or $CaCl_2$ (ethyl acetate). (–)-(*S*)-α-Methylbenzylamine and (+)-(*R*)-α-methylbenzylamine were commercial chemicals (Merck); they were used without additional puification.

***tert*-Butyl(isobutyl)-α-methylbenzylaminophosphine (IIa).** A solution of 0.02 mol of α-methylbenzylamine in 5 ml of benzene was added with stirring to a solution of 0.02 mol of *tert*-butyl(chloro)isobutylphosphine and 3.5 ml of triethylamine in 10 ml of benzene. The mixture was stirred for 2–3 h at room temperature and was left overnight. The precipitate of triethylamine hydrochloride was filtered off and washed with diethyl ether. The filtrate was evaporated, and the residue was distilled under reduced pressure. Yield 70%. Colorless liquid, bp 85–90°C (0.08 mm). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 51.13, 50.035. Found P, %: 11.82. $C_{16}H_{28}NP$. Calculated P, %: 11.67.

(S_P,*S*)/(R_P,*S*)-*tert*-Butyl(α-methylbenzylamino)phenylphosphine (IIc). A solution of 0.02 mol of (–)-(*S*)-α-methylbenzylamine and 0.022 mol of triethylamine in 5 ml of toluene was slowly added (over a period of 3 h) with stirring to a solution of 0.02 mol of *tert*-butyl(chloro)phenylphosphine in 10 ml of toluene. The mixture was stirred for 2–3 h at room temperature and was left overnight. The precipitate of triethylamine hydrochloride was filtered off and washed with 50 ml of diethyl ether. The filtrate was evaporated, and the residue was distilled under reduced pressure. The reaction was carried out under different conditions. Depending on the nature of the base and solvent, different diastereoisomer ratios were obtained. Yield 80%. Colorless liquid, bp 130–135°C (0.02 mm). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.77 d [$(CH_3)_3C$, $^3J_{HP}$ 5.0], 0.81 d [$(CH_3)_3C'$, $^3J_{HP}$ 7.0], 1.60 m (CH), 1.45 d (CH_3, $^3J_{HH}$ 7.0), 1.51 d (CH'_3, $^3J_{HH}$ 7.0), 3.54 m (NH), 7.10–7.33 m (C_6H_5). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 49.9, 47.24 (diastereoisomer ratio 8 : 92). Found P, %: 10.61. $C_{18}H_{24}NP$. Calculated P, %: 10.85.

(S_P)-*tert*-Butyl(α-methylbenzylamino)phenylphosphine–borane complex (III). A solution of 0.3 mol of BH_3 in tetrahydrofuran was added to a solution of 0.1 mol of (S_P)/(R_P)-*tert*-butyl(α-methylbenzylamino)phenylphosphine in 5 ml of THF. The resulting transparent solution was evaporated under reduced pressure to isolate a crystalline product which was recrystallized from hexane. Yield 90%, mp 140–141°C (from hexane), $[\alpha]_D$ +24.5° (*c* 0.01, CH_2Cl_2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.2–2 m (3H, BH_3), 1.01 d [9H, $(CH_3)_3C$, $^3J_{HP}$ 14.16], 1.50 d (3H, CH_3, $^3J_{HH}$ 6.72), 2.07 br.d (1H, NH, $^2J_{HP}$ 16.0), 4.45 m (1H, CHN), 7.10–7.40 m (10H, C_6H_5). ^{13}C NMR spectrum ($CDCl_3$), δ_C, ppm (*J*, Hz): 24.57 d [$(CH_3)_3C$, $^2J_{CP}$ 2.76], 25.57 d [(CH$_3$)CHN, $^3J_{CP}$ 5.20], 30.69 d [$(CH_3)_3C$, $^1J_{CP}$ 43.40], 52.47 d (CHN, $^2J_{CP}$ 2.01), 126.10 s, 126.94 s, 127.58 d (J_{CP} 9.50), 130.37 d (J_{CP} 2.50), 130.75 d (J_{CP} 46.80), 131.94 d (J_{CP} 9.40) (C_6H_5). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm (*J*, Hz): 69.76 d ($^1J_{BP}$ 42.93). Found, %: N 4.85; P 10.61. $C_{18}H_{27} \cdot BNP$. Calculated, %: N 4.68; P 10.35.

(S_P,*S*)-*tert*-Butyl(α-methylbenzylamino)phenylphosphine (IIb). A solution of 0.1 mol of complex **III** in 3 ml of diethylamine was left to stand overnight at 50°C. The solvent was distilled off, and the residue was distilled in a high vacuum. The ^{31}P NMR spectrum of the product contained only one signal belonging to the (S_P)-diastereoisomer, which was confirmed by comparison with the spectrum of an artificial mixture of diastereoisomers (10 : 1). Yield 50%, bp 160–161°C (0.02 mm). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.81 d [9H, $(CH_3)_3C$, $^3J_{HP}$ 7.0], 1.60 m (1H, NH), 1.45 d (3H, CH_3, $^3J_{HH}$ 14.0), 3.54 m (1H, CHN), 7.10–7.33 m (10H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 49.00 ppm.

Mesityl(α-methylbenzylamino)phenylphosphine (IIc) was synthesized as described above for compound **IIa**. Yield 85%. Filtration of the reaction mixture, followed by removal of the solvent, gave a viscous liquid which could not be distilled under reduced pressure. The product was characterized by spectral data and was brought into further transformations without additional purification. ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 29.75, 29.23.

***tert*-Butyl(isobutyl)(α-methylbenzylamino)phosphine oxide (IVa)** was synthesized as described below for compound **IVb**. Yield 64%, mp 171–172°C (from diethyl ether); $[\alpha]_D$ –44.8° (*c* 1, benzene). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.00 m [6H, $(CH_3)_2C$], 1.12 d [9H, $(CH_3)_3C$, J_{HP} 20], 1.53 d (3H, CH_3, J_{HH} 6.5), 1.51 m (2H, CH_2), 2.08 m (1H, CHC), 4.57 d (1H, NH), 7.00–7.31 m (5H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 52.92 ppm. Found, %: N 4.96; P 10.81. $C_{16}H_{28}NOP$. Calculated, %: N 4.98; P 11.01.

(*S*,*S*)/(*S*,*R*)-*tert*-Butyl(α-methylbenzylamino)-phenylphosphine oxide (IVb). Excess carbon tetrachloride was added on cooling to a solution of aminophosphine **IIb** in diethyl ether. The mixture was allowed to warm up to room temperature and cooled again, and excess methanol was added. The mixture was left to stand for 1 h and evaporated. The residue was a viscous liquid which was diluted with hexane, and the mixture was left to stand overnight for crystallization. The crystalline product was filtered off and recrystallized from ethyl acetate. The mother liquor was evaporated, and the residue was subjected to column chromatography on silica gel using hexane–2-propanol (92:8) as eluent.

(*R*,*R*)-Diastereoisomer. Yield 5%, mp 142–144°C, $[\alpha]_D$ –125.5 (*c* 1, heptane). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.04 d [9H, $(CH_3)_3C$, *J* 14.4], 1.48 d (3H, CH_3C, *J* 7.4), 2.76 d.d (1H, NH, *J* 7), 2.99 m (3H, CH_3C), 4.17 br (1H, CH), 7.13–7.57 m (10H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 42.86. **(*S*,*R*)-Diastereoisomer.** Yield 70%, mp 171–172°C (from ethyl acetate), $[\alpha]_D$ –82.5° (*c* 0.5, ethanol). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.01 d [9H, $(CH_3)_3C$, J_{HP} 14.8], 1.33 d (3H, CH_3, J_{HP} 7.0), 2.80 br (1H, NH), 4.44 br (1H, CH, J_{HH} 8.0), 7.19–7.4 m and 7.87 m (10H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 41.32 ppm. Found, %: N 4.67; P 10.42. $C_{18}H_{24}NOP$. Calculated, %: N 4.65; P 10.28.

Mesityl(α-methylbenzylamino)phenylphosphine oxide (IVc) was synthesized as described above for compound **IVb**. **(*S*,*S*$_P$)-Diastereoisomer.** Yield 50%, mp 157°C (from ethyl acetate), $[\alpha]_D$ +10° (*c* 1, ethanol). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.67 d (3H, PhCH*Me*, J_{HH} 7), 2.29 s (3H, 4-Me), 2.38 s (6H, 2-Me, 4-Me), 3.00 m (1H, NH, J_{HH} 9.0, J_{PH} 9.0), 4.5 m (1H, PhC*H*Me), 6.9 d (2H, 3-H, 5-H, J_{PH} 4.0), 7.2–7.4 m (5H, C_6H_5), 7.35 m (5H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 28.0 ppm [9].

Alcoholysis of (+)-(S_P,*S*)-mesityl(α-methylbenzylamino)phenylphosphine (IIc). A mixture of 18.2 mmol of (+)-(S_P,*S*)-mesityl(α-methylbenzylamino)phenylphosphine, 85 ml of methanol, and 1.6 ml of 98% sulfuric acid was heated for 5 h under reflux. The mixture was cooled, 200 ml of chloroform was added, and the mixture was washed with a 10% aqueous solution of sodium hydrogen carbonate (3 × 50 ml) and water (2 × 50 ml). The organic phase was dried over magnesium sulfate and concentrated under reduced pressure. The residue was a colorless liquid (6.17 g) which was purified by flash chromatography on silica gel. We thus isolated methyl (–)-(*R*)-phenyl(2,4,6-trimethylphenyl)phosphinate as a colorless liquid. Yield 4.0 g (80%), $[\alpha]_D$ –20° (*c* 0.33, ethanol) [9]. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 2.3 s (3H, 4-CH_3), 2.50 d (6H, 2-CH_3, 6-CH_3, J_{PH} 1.2), 3.70 d (3H, OCH_3, J_{PH} 11.1), 6.90 d (2H, 3-H, 5-H, J_{PH} 4.2), 7.5 m (3H, C_6H_5), 7.60 m (2H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 37.0 ppm.

***tert*-Butyl(α-methylbenzylamino)phenylphosphine sulfide (Vb).** To a solution of aminophosphine **IIb** in benzene, cooled to 0–5°C, we added a solution of 1.1 equiv of sulfur in benzene. The mixture was allowed to warm up to room temperature and was left to stand for 1 h. The solvent was evaporated to obtain a viscous liquid which was diluted with hexane and was left overnight for crystallization. The crystalline product was filtered off and recrystallized from ethyl acetate. The mother liquor was evaporated, and the residue was subjected to column chromatography on silica gel using hexane–2-propanol (92:8) as eluent. **(S_P,*S*)-Diastereoisomer.** Yield 50%, mp 105–106°C (from hexane), $[\alpha]_D$ –66° (*c* 1, $CHCl_3$). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.98 d [9H, $(CH_3)_3C$, J_{HP} 16.6], 1.21 d (3H, CH_3, J_{HH} 6), 2.21 br (1H, NH), 4.67 d.d (1H, CH, J_{HP} 6.6), 7.2 m and 7.93 m (10H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 80.74 ppm. **(R_P,*S*)-Diastereoisomer.** Yield 8%. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.98 d [$(CH_3)_3C$, J_{HP} 16.6], 1.21 d (CH_3, J_{HH} 6.0), 2.21 m (NH), 4.41 d.d (CH, J_{HH} 6.0, J_{HP} 8), 7.2 m and 7.93 m (C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 78.10 ppm. Found, %: N 4.45; P 9.62. $C_{18}H_{24}NPS$. Calculated, %: N 4.41; P 9.76.

***tert*-Butyl(isobutyl)-α-methylbenzylaminophosphine sulfide (Va)** was synthesized as described above for compound **Vb**. Yield 40%, mp 116–117°C (from diethyl ether). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.74 d [6H, $(CH_3)_2C$, J_{HH} 6.6], 1.19 d [9H, $(CH_3)_3C$, J_{HP} 16.2], 1.49 d (3H, CH_3, J_{HH} 6.6), 1.63 m (2H, CH_2P), 2.04 br (1H, CHC), 4.73 br (1H, CHN), 7.26 m and 7.34 m (5H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 84.58 ppm. Found N, %: 4.8. $C_{16}H_{28}NPS$. Calculated N, %: 4.91.

(S_P,S)-*tert*-Butyl(methyl)(α-methylbenzylamino)-phenylphosphonium iodide (VI). Methyl iodide, 0.015 mol, was added to a solution of 0.01 mol of *tert*-butyl(α-methylbenzylamino)phenylphosphine in 5 ml of toluene, and the mixture was left overnight. The product was filtered off and recrystallized. Yield 84%, mp 220–221°C (from $C_2H_5OH \cdot H_2O$, 1 : 10), $[\alpha]_D$ –7.3 (*c* 2.5, C_2H_5OH). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.21 d [9H, $(CH_3)_3C$, J_{HP} 16], 1.51 d (3H, CH_3, *J* 6.5), 2.45 d (3H, CH_3P, J_{HP} 11.5), 4.11 br (1H, CH), 6.14 br (1H, NH), 7.30 m (10H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 55.8 ppm. Found, %: N 3.33; P 7.29. $C_{19}H_{27}INP$. Calculated, %: N 3.28; P 7.25. Compound **VI** was converted into readily crystallizable perchlorate. For this purpose, it was dissolved in a minimal amount of water, and an aqueous solution of sodium perchlorate was added. The precipitate was filtered off and purified by recrystallization.

(S_P,S)-*tert*-Butyl(methyl)(α-methylbenzylamino)-phenylphosphonium perchlorate. Yield 60%, mp 242–243°C (from C_2H_5OH–H_2O, 1 : 10). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.11 d [9H, $(CH_3)_3C$, J_{HP} 21], 0.99 m (2H, CH_2), 1.85 d (3H, CH_3, J_{HH} 8), 2.77 m (3H, CH_3P), 3.77 m (1H, CHC), 5.89 d (1H, NH), 7.05–7.26 m (5H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 57.48 ppm. Found N, %: 3.44. $C_{19}H_{27}ClNO_4P$. Calculated N, %: 3.50.

(α)-(S)-*tert*-Butylphenylphosphine oxide (VII). A solution of 0.01 mol of formic acid was added dropwise with stirring to a solution of 0.01 mol of (S_P,S)-*tert*-butyl(α-methylbenzylamino)phenylphosphine in 10 ml of toluene, cooled to –50°C. The mixture was allowed to warm up to room temperature and was left to stand for 1 h. The precipitate was filtered off, the filtrate was evaporated under reduced pressure, and the residue was extracted with hexane. The extract was evaporated to obtain spectroscopically pure compound **VII** which may be purified (if necessary) by column chromatography on silica gel using benzene as eluent. The product is readily oxidized on exposure to air. Yield 80%, $[\alpha]_D$ –44.6° (*c* 1, toluene); published data [10–12]: $[\alpha]_D$ –40.45° (*c* 1.78, MeOH). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.018 d [9H, $(CH_3)_3C$, J_{HP} 17], 7.05–7.95 m (5H, C_6H_5), 5.29 d (1H, PH, $^1J_{PH}$ 454). ^{31}P NMR spectrum ($CDCl_3$): δ_P 48.17 ppm, d ($^1J_{PH}$ 454 Hz).

Phenylphosphonous bis(α-methylbenzylamide) (Xa). A solution of 0.01 mol of dichloro(phenyl)-phosphine in 10 ml of diethyl ether was added dropwise with stirring to a solution of 0.02 mol of (–)-(S)-α-methylbenzylamine and 0.02 mol of triethylamine in 10 ml of diethyl ether, cooled to –70°C. The mixtue was allowed to warm up to room temperature and was stirred for 2 h. The precipitate of triethylamine hydrochloride was filtered off, and the filtrate was evaporated. The residue was phenylphosphonous bis-(α-methylbenzylamide) (**Xa**) as a viscous oil. Yield ~95%. ^{31}P NMR spectrum ($CDCl_3$): δ_P 60.1 ppm (cf. [4]).

Phenylphosphonic bis(α-methylbenzylamide) (XIIa). Compound **Xa** was synthesized as described above. After removal of the solvent, the residue was dissolved in anhydrous dioxane, the solution was cooled to –20°C, a solution of 0.0125 mol of hydrogen peroxide in 10 ml of dioxane was added, and the mixture was left to stand for 1 h. The solvent was removed under reduced pressure, and the residue was recrystallized from hexane. Yield 80%, mp 70°C. ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.25 d (3H, CH_3, $^3J_{HH}$ 7.0), 1.42 d (3H, CH_3, $^3J_{HH}$ 7.0), 2.65 m (1H, NH), 2.79 m (1H, NH), 4.3 m (1H, CH), 4.5 m (1H, CH), 6.8–7.5 m (15H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 19 ppm. Found N, %: 7.40. $C_{22}H_{25}N_2OP$. Calculated N, %: 7.68.

Phenylphosphonothioic bis(α-methylbenzylamide) (XIIIa). Crude compound **Xa** (see above) was dissolved in benzene, an equimolar amount of finely powdered elemental sulfur was added, and the mixture was left overnight. The solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel using hexane–ethyl acetate (5 : 1) as eluent. Yield 80%, yellowish oily substance. ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.25 d (3H, CH_3, $^3J_{HH}$ 7.0), 1.42 d (6H, CH_3, $^3J_{HH}$ 7.0), 2.65 m (2H, CH), 4.3 m (2H, NH), 6.8–7.5 m (15H, C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 65 ppm. Found, %: N 7.11; S 8.45. $C_{22}H_{25}N_2PS$. Calculated, %: N 7.35; S 8.43.

***p*-Fluorophenylphosphonothioic bis(α-methylbenzylamide) (XIIIb)** was synthesized as described above for compound **XIIIa**. Yield 50%, mp 105–106°C (from toluene–hexane, 5 : 1), $[\alpha]_D$ –28.18° (*c* 1, $CHCl_3$). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.28 d (CH_3, J_{HH} 7.0), 1.42 d (CH_3, J_{HH} 7.0), 2.65 m (CH), 4.3 (NH), 6.8–7.7 m (C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 62.33 ppm. Found, %: N 7.15; P 8.27. $C_{22}H_{24}FN_2PS$. Calculated, %: N 7.03; P 8.03.

***p*-Dimethylaminophenylphosphonothioic bis-(α-methylbenzylamide) (XIIIc)** was synthesized as described above for compound **XIIIa**. Yield 60%, mp

131–132°C (from toluene–hexane, 5 : 1), $[\alpha]_D$ –14.81° (*c* 1, $CHCl_3$). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.25 d (3H, CH_3, $^3J_{HH}$ 7.5), 1.35 d (3H, CH_3, $^3J_{HH}$ 7.5), 2.55 m (2H, CH), 2.99 s (6H, CH_3N), 4.44 m (2H, NH), 6.53–7.84 m (9H, C_6H_5, C_6H_4). ^{31}P NMR spectrum ($CDCl_3$): δ_P 64.42 ppm. Found S, %: 7.99. $C_{24}H_{30}N_3PS$. Calculated S, %: 7.55.

***tert*-Butylphosphinic α-methylbenzylamide (XIVe).** Formic acid, 0.01 mol, was added with stirring and cooling to a solution of 0.01 mol of *tert*-butylphosphonous bis(α-methylbenzylamide) in toluene. The mixture was allowed to warm up to room temperature and was left overnight. The precipitate was filtered off, the filtrate was evaporated, and the residue was distilled under reduced pressure. Yield 70%, bp 135°C (0.4 mm), $[\alpha]_D$ –91.5° (toluene). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 0.79 d [9H, $(CH_3)_3C$, J_{PH} 16.5], 1.45 d (3H, CH_3, J_{HH} 7), 4.2 q (1H, CHN, J_{HH} 7), 5.14 m (1H, NH), 7.8 m (5H, C_6H_5), 6.33 d (1H, PH, $^1J_{PH}$ 494). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 39.31 d ($^1J_{PH}$ 495 Hz). Found P, %: 13.39. $C_{12}H_{20}NOP$. Calculated P, %: 13.75.

Methylphosphinic α-methylbenzylamide (XIVd) was synthesized as described above for compound **XIVe**. Yield 78%, bp 120°C (0.05 mm), $[\alpha]_D$ –101.6° (*c* 1, toluene). ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.35 d (3H, CH_3, J_{HH} 7.3), 1.43 d (3H, CH_3, J_{HH} 7.0), 4.2 q (1H, CHN, J_{HH} 7), 4.97 m (1H, NH), 7.05–7.95 m (5H, C_6H_5), 6.00 d (1H, PH, $^1J_{PH}$ 496). ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 20.54 d ($^1J_{PH}$ 496 Hz). Found P, %: 16.35. $C_9H_{14}NOP$. Calculated P, %: 16.91.

Phosphorous tris(α-methylbenzylamide)borane complex (XVf). *a*. **Phosphorous tris(α-methylbenzylamide) (VIII).** A solution of 0.01 mol of phosphorus(III) chloride in 10 ml of diethyl ether was added dropwise under stirring to a solution of 0.033 mol of (–)-(*S*)-α-methylbenzylamine and 0.033 mol of triethylamine in 15 ml of diethyl ether, cooled to –70°C. The mixture was allowed to warm up to room temperature and was stirred for 0.5 h. The precipitate of triethylamine hydrochloride was filtered off, and the filtrate was evaporated to obtain phosphorous tris(α-methylbenzylamide) (**VIII**) as a viscous liquid. Yield ~90%. ^{31}P NMR spectrum ($CDCl_3$): δ_P 104.8 ppm [4].

b. **Borane complex (XVe).** Compound **VIII** was quickly dissolved in THF, a solution of an equimolar amount of borane in THF was added, and the mixture was left overnight. The solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel using hexane–ethyl acetate (6 : 1) as eluent. Yield 50%. ^1H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 1.35 d (CH_3, $^3J_{HH}$ 7.0), 1.42 d (CH_3, $^3J_{HH}$ 7.0), 2.3 m (NH), 4.3 m (2H, CH), 7.0–7.3 m (C_6H_5). ^{31}P NMR spectrum ($CDCl_3$): δ_P 84.88 ppm ($^1J_{PB}$ 50 Hz). Found, %: N 10.11; P 7.45. $C_{24}H_{33}BN_3P$. Calculated, %: N 10.37; P 7.64.

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