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Synthesis and structural characterization of *N*-[2-(diphenylphosphorothioyl)phenyl]-2-(phenylamino)benzamide

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Dedicated to Acad. Bogdan Kurtev on the occasion of his 100th birth anniversary

N-(2-(diphenylphosphorothioyl)phenyl)-2-(phenylamino)benzamide with perspective application as a ligand in organometallic homogeneous catalysis was prepared using *N*-phenylanthranilic acid as starting material. Its structure was studied by NMR spectroscopy and X-ray diffraction.

Key words: organophosphorous compounds; one-pot; homogeneous catalysis ligand

INTRODUCTION

Compounds containing phosphorous and nitrogen atom which can coordinate to a transition metal, as well as their respective complexes are subject of research in recent decades [1−4]. Interest in them has increased after discovering of the reactions of Negishi, Heck and Suzuki [5−7], which are catalysed by a palladium complex, usually bearing a phosphine ligand. In this work we present the results of the multistep synthesis and X-ray analysis of a potential (2-aminophenyl)diphenylphosphine sulphide derived ligand. We aimed to obtain an organophosphorus compound, which can be used as a ligand in homogeneous catalysis and as a starting material for the preparation of P-functionalized NHC-precursors.

EXPERIMENTAL

Synthesis

All solvents and chemicals were purchased from commercial suppliers. Petroleum ether was used as received. Dichloromethane was dried over anhydrous $CaCl_2$ and distilled. Toluene was distilled from sodium/benzophenone and stored under argon. Silica gel 0.035-0.070 mm, 60 A was used for flash chromatography. TLC on silica gel 60 F_{254} on aluminium sheets was used for monitoring of the reactions.

The NMR spectra of (**5**) were recorded on a Bruker Avance II+ 600 (600.13 for ^{1}H NMR, 150.92 MHz for ^{13}C NMR and 242.92 MHz for ^{31}P NMR) spectrometer with a reference TMS (85% H_3PO_4 for ^{31}P) as internal standard or chemical shifts of residue solvent peaks (δ, ppm). ^{1}H and ^{13}C NMR data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants J (Hz), integration and identification. The atom numbering follows Fig.1.

In a Schlenk flask equipped with condenser were mixed 0.77 g (3.6 x 10^{-3} mol) *N*-phenylanthranilic acid (**1** on Scheme 1) and 8 ml dry toluene. 0.75 mL (1.028 x 10^{-2} mol) of thionyl chloride were added and the mixture was stirred for 15 minutes at room temperature, 25 min at 100 °C, and then 10 minutes at 125 °C. The volatile components of the reaction mixture were removed under reduced pressure to leave the desired chloride (**2** on Scheme 1).

20 ml of dry toluene, 1 g (3.6 x 10^{-3} mol) of 2-(diphenylphosphanyl)aniline (**3** on Scheme 1) and 0.29 ml (3.63 x 10^{-3} mol) of dry pyridine were mixed in a separate Schlenk tube and the resulting solution was degassed.

The prepared acid chloride **2** was dissolved in 8 ml of dry toluene and degassed. The resulting solution was added in one portion to the solution of 2-(diphenylphosphanyl)aniline (**3**) (Scheme 1). The reaction mixture thus obtained was stirred at room temperature until no starting aniline (about 24 hours) remains (TLC). Then 0.127 g (3.97 x 10^{-3} mol) of sulphur was added. The stirring continued

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15 hours at room temperature until no more *N*-(2-(diphenylphosphanyl)phenyl)-2-(phenylamino) benzamide (**4** on Scheme 1) could be observed with TLC. The resulting reaction mixture was diluted with an equal volume of ethyl acetate, washed three times with 25 ml portions of brine, dried over anhydrous Na_2SO_4 and the solvent evaporated under reduced pressure. The crude product was purified by flash chromatography on 36 g silica gel, using methylene chloride:petroleum ether = 2:3 as a mobile phase. Yield: 1,4 g (77%) of pale yellow crystals.

^{1}H NMR (600 MHz, $CDCl_3$) δ= 6.75 (ddd, J=1.1, 7.0, 8.0 Hz, 1H, **H-C4**), 6.84 (ddd, J=1.3, 7.8, $^3J_{P\text{-}H}$=14.3 Hz, 1H, **H-C15**), 7.01 (tt, J=1.1, 7.3 Hz, 1H, **H-C10**), 7.11 (ddd, J=1.10, 7.60, , $^4J_{P\text{-}H}$= 2.3, 1H, **H-C16**), 7.13 (dd, J=1.1, 8.5 Hz, 2H, **H-C12, H-C8**), 7.23 (ddd, J=1.3, 7.0, 8.4 Hz, 1H, **H-C3**), 7.27 (dd, J=1.1, 8.4 Hz, 1H, **H-C2**), 7.30 (dd, J=7.3, 8.5 Hz, 2H, **H-C11, H-C9**), 7.38-7.42 (m, 6H, **Ar**-P), 7.52 (dd, J=1.3, 8.0 Hz, 1H, **H-C5**), 7.61 (ddd, J=1.3, 7.6, 8.2 Hz, 1H, **H-C17**), 7.70-7.75 (m, 4H, **Ar**-P), 8.08 (ddd, J=1.1, 8.2 Hz, $^4J_{P\text{-}H}$= 5.0, 1H, **H-C18**), 9.30 (bs, 1H , **N1-H**), 10.31 (s, 1H, **N2-H**).

^{13}C-NMR (151, $CDCl_3$) δ= 115.06 (**C2**), 116.87 (**C6**), 118.03 (**C4**), 120.73 (**C12, 8**), 122.39 (**C10**), 124.31 (d, J=85.5 Hz, **C26, C20**), 124.55 (d, $^3J_{C\text{-}P}$=12.2 Hz, **C16**), 126.39 (d, $^3J_{C\text{-}P}$ =6.9 Hz, **C18**), 128.42 (**C5**), 128.73 (d, J=12.9 Hz, **Ar**-P), 129.06 (**C11, 9**), 130.37 (d, J=86.2 Hz, **C19**), 132.33 (**Ar**-P), 132.35 (**Ar**-P), 132.42 (**C15**), 132.70 (**C3**), 132.92 (d, $^4J_{C\text{-}P}$ =2.1 Hz, **C17**), 141.06 (d, J=4.3 Hz, **C14**), 141.49 (**C7**), 145.86 (**C1**), 167.65 (**C13**).

^{31}P NMR (243 MHz, $CDCl_3$) δ= 40.01 (s, **P1**).

X-ray crystallography

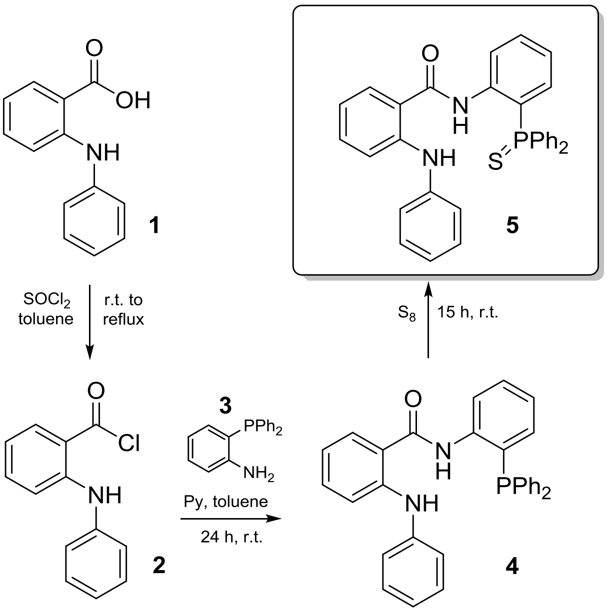
Pale yellow crystals of **5**, suitable for X-ray analysis were obtained by slow evaporation at room temperature from a solution of dichloromethane and petroleum ether.

Crystal was mounted with the help of light hydrocarbon oil on Bruker SMART X2S diffractometer and data were collected using graphite monochromated Mo Kα radiation (κ=0.71073 Å). The data integration and reduction were processed with APEX software. An absorption correction was applied [8]. The structure was solved by the direct method using SHELXS-97 and was refined on F^2 by full-matrix least-squares technique using the SHELXL-97 software package [9] and Olex2 [10]. Nonhydrogen atoms were refined anisotropically. In the refinement, hydrogen atoms were treated as riding atoms using SHELXL default parameters.

RESULTS AND DISCUSSION

Synthesis

The synthesis of the target compound is presented on Scheme 1.



Scheme 1. Synthesis of **5**.

N-phenylanthranilic acid (**1**) was reacted [11] with $SOCl_2$ in dry toluene in inert Ar atmosphere. After evaporation of the volatiles the acid chloride (**2**) was mixed with 2-(diphenylphosphanyl)aniline [12−14] in the presence of pyridine. The P(III) atom of thus obtained benzamide (**4**) was protected by oxidation to P(V) with elemental sulfur. Finally the target compound (**5**) was purified by column chromatography and obtained with very good overall yield as yellow crystals.

^{1}H-NMR of *N*-(2-(diphenylphosphorothioyl) phenyl)-2-(phenylamino)benzamide was recorded in deuterated chloroform. The spectrum of (**5**) shows signals at high frequency for the two nitrogen protons, respectively at 9.3 and 10.3 ppm (see Fig. S1 for the actual ^{1}H, ^{13}C and ^{31}P NMR spectra), which may be attributed to hydrogen-bond type interactions with S=P and O=C-groups. Signals of the carbon atoms of Ar-P fragment are split due to coupling with the phosphorus atom.

X-ray crystallography

Crystal data and data collection parameters for the compound (**5**) are presented in Table 1.

Table 1. Crystal data and structure refinement for **5**.

Identification code	5
Empirical formula	$C_{31}H_{25}N_2OPS$
Formula weight	504.56
Temperature/K	300.15
Crystal system	Triclinic
Space group	*P*-1
a/Å	11.3475(17)
b/Å	11.4393(18)
c/Å	12.429(2)
α/°	106.973(5)
β/°	105.855(5)
γ/°	110.912(5)
V/Å^3	1306.5(4)
Z	2
ρ_{calc}g/cm^3	1.283
μ/mm^{-1}	0.212
F(000)	528.0
Crystal size/mm^3	0.4 × 0.3 × 0.05
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	3.78 to 52.632
Index ranges	$-13 \leq h \leq 14$, $-14 \leq k \leq 14$, $-14 \leq l \leq 15$
Reflections collected/independent	9408/5093
Data/restraints/parameters	5093/0/325
Goodness-of-fit on F^2	0.959
Final R indexes [I>=2σ (I)]	R = 0.0630, wR = 0.1394
Final R indexes [all data]	R = 0.1422, wR = 0.1831
Largest diff. peak/hole / e Å^{-3}	0.27/-0.38

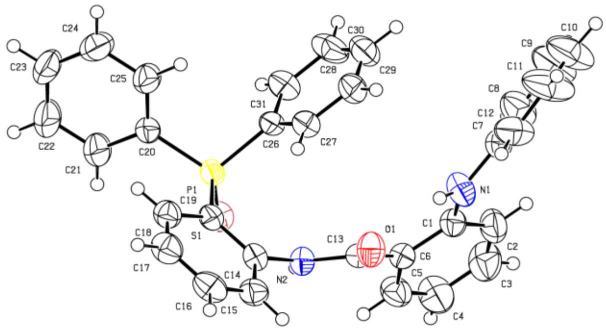


Fig. 1. ORTEP drawing of molecular structure of **5**. The thermal displacement ellipsoids are drawn at the 50% probability.

CCDC 1403430 contains the supplementary crystallographic data for (**5**). These data can be obtained from the Cambridge Crystallographic Data Centre. ORTEP drawing of molecular structure of (**5**) is depicted on Fig. 1.

Compound (**5**) crystallizes in the triclinic system and space group *P-1*. The bond lengths and angles are shown in Tables 2 and 3.

Table 2. Observed bond lengths in **5**.

Bond	Length Å	Bond	Length Å
P1–S1	1.9698(16)	C7–C8	1.392(6)
P1–C26	1.824(3)	C27–C28	1.380(5)
P1–C19	1.824(3)	C1–C2	1.405(6)
P1–C20	1.808(4)	C15–C16	1.377(6)
O1–C13	1.239(4)	C18–C17	1.378(5)
N2–C14	1.420(5)	C17–C16	1.376(6)
N2–C13	1.380(4)	C25–C24	1.392(6)
N1–C7	1.407(5)	C31–C30	1.390(5)
N1–C1	1.390(5)	C5–C4	1.372(6)
C14–C19	1.408(5)	C28–C29	1.371(6)
C14–C15	1.387(5)	C29–C30	1.370(6)
C26–C27	1.386(5)	C12–C11	1.374(6)
C26–C31	1.390(5)	C24–C23	1.369(6)
C19–C18	1.382(5)	C23–C22	1.377(7)
C13–C6	1.484(6)	C2–C3	1.369(6)
C20–C25	1.379(6)	C8–C9	1.381(6)
C20–C21	1.387(5)	C21–C22	1.380(6)
C6–C1	1.424(5)	C4–C3	1.391(6)
C6–C5	1.394(6)	C11–C10	1.387(7)
C7–C12	1.372(6)	C9–C10	1.348(7)

The carbonyl oxygen and NHPh-group are slightly out from the plane of the anthranilic C_6H_4-ring. The geometry at the P atom is tetrahedral; the P=S distance is 1.9681 Å and the average P-C distance is 1.8157 Å. The average C-P-S angle is 112.84° and an average C-P-C angle is 105.9°. The average length of the P-S bond in **5** is longer than that of triphenylphosphine sulfide, due to substituents in the phenyl ring [15]. The average P–C bond and C–P–C angle in **5** and in the reference Ph_3P=S are similar [15]. The crystal structure of **5** shows intramolecular hydrogen bonding interactions between oxygen and hydrogen and between sulphur and hydrogen (Table 4).

Table 4. Details of hydrogen bonds observed in **5**.

D*–H···*A	***D*···*A* [Å]**	**H···*A* [Å]**	***D*–H–*A* [°]**
N1–H···O1	2.739	2.048	136.87
N2–H···S1	3.305	2.698	128.70

Table 3. Observed angles in **5**.

Angle	**[°]**	**Angle**	**[°]**
C26–P1–S1	113.52(14)	C8–C7–N1	123.4(4)
C19–P1–S1	112.12(14)	C28–C27–C26	120.8(4)
C19–P1–C26	105.67(16)	N1–C1–C6	119.2(4)
C20–P1–S1	112.82(14)	N1–C1–C2	123.1(4)
C20–P1–C26	105.74(17)	C2–C1–C6	117.7(4)
C20–P1–C19	106.36(18)	C16–C15–C14	120.0(4)
C13–N2–C14	122.4(3)	C17–C18–C19	121.6(4)
C1–N1–C7	129.7(4)	C16–C17–C18	119.6(4)
C19–C14–N2	121.0(3)	C17–C16–C15	120.5(4)
C15–C14–N2	119.0(3)	C20–C25–C24	121.3(4)
C15–C14–C19	120.1(3)	C30–C31–C26	119.7(4)
C27–C26–P1	123.0(3)	C4–C5–C6	122.7(4)
C27–C26–C31	118.9(3)	C29–C28–C27	119.8(4)
C31–C26–P1	118.0(3)	C30–C29–C28	120.4(4)
C14–C19–P1	120.0(3)	C7–C12–C11	120.8(4)
C18–C19–P1	121.8(3)	C23–C24–C25	119.6(5)
C18–C19–C14	118.2(3)	C24–C23–C22	119.9(5)
O1–C13–N2	121.3(4)	C3–C2–C1	121.2(4)
O1–C13–C6	122.9(3)	C29–C30–C31	120.3(4)
N2–C13–C6	115.8(4)	C9–C8–C7	119.9(5)
C25–C20–P1	121.7(3)	C22–C21–C20	120.7(5)
C25–C20–C21	118.2(4)	C5–C4–C3	118.0(5)
C21–C20–P1	120.2(4)	C2–C3–C4	121.5(5)
C1–C6–C13	120.6(4)	C23–C22–C21	120.3(4)
C5–C6–C13	120.5(3)	C12–C11–C10	120.4(5)
C5–C6–C1	118.9(4)	C10–C9–C8	121.4(5)
C12–C7–N1	118.1(4)	C9–C10–C11	118.8(5)
C12–C7–C8	118.4(4)		

CONCLUSION

The synthesis and detailed structure elucidation of *N*-[2-(diphenylphosphorothioyl)phenyl]-2-(phenylamino)benzamide (**5**) are reported. This compound can serve as both a phosphinotioate and after P-deprotection - as a phopshine ligand as well. The title compound opens further synthetic possibilities to 4-oxo-3,4-dihydroquinazolin-1-ium carbene precursors. The single crystal structure of *N*-(2-(diphenylphosphorothioyl)phenyl)-2-(phenylamino)benzamide (**5**) has been studied, giving insight into its capabilities as a bidentate ligand to accommodate metal atoms. Two different type of hydrogen-acceptor interactions in **5** have been observed as well.

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Electronic Supplementary Data available here.

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СИНТЕЗ И СТРУКТУРНО ОХАРАКТЕРИЗИРАНЕ НА *N*-(2-(ДИФЕНИЛФОСФОРОТИОИЛ)ФЕНИЛ)-2-(ФЕНИЛАМИНО)БЕНЗАМИД

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(Резюме)

N-(2-(дифенилфосфоротиоил)фенил)-2-(фениламино)бензамид, с перспективно приложение като лиганд в органометалния хомогенен катализ беше получен чрез синтез в няколко стъпки от изходно вещество N-фенилантранилова киселина. Неговата структура беше изучена чрез ЯМР-спектроскопия и рентгеноструктурен анализ.