Cobalt Complexes with 1,3-Bis(trimethylsilyl)cyclopentadienyl and Substituent-Free P_n Ligands

Otto J. Scherer,*[a] **Thomas Völmecke,**[a] **and Gotthelf Wolmershäuser**[a][+]

Keywords: Phosphorus / P_n / $C_5H_3(SiMe_3)_2$ ligands / Cobalt / Coordination chemistry / Crystallography

The thermal or photochemical reaction of $[Cp''Co(CO)_2]$ (**1**) $[Cp'' = C_5H_3(SiMe_3)_2\text{-}1,3]$ with white phosphorus (P_4) gives $[\{Cp''Co\}_2(P_5\text{–}P_5)\{CoCp''\}_2]$ (**2**) and $[\{Cp''Co\}_3P_4(\mu\text{-}CO)]$ (**3**) as well as $[\{Cp''Co\}_2(\mu\text{-}\eta^2:\eta^2\text{-}P_2)_2]$ (**4**). Cobalt complexes **2**, **3**, and **4** have been characterized by an X-ray crystal-structure determination.

Introduction

In the chemistry of transition-metal complexes with substituent-free ("naked") P_n ligands the choice of the additional Cp^R ligands plays an important role.[1] Illustrative examples are the reactions of $[\{Cp^R(OC)_2Fe\}_2](Fe\text{–}Fe)$ with white phosphorus (P_4).

Starting with $Cp^R = C_5H_5$ the cothermolysis gives the tetranuclear cluster $[\{CpFe\}_4(P_2)_2]$ with a triangulated dodecahedral Fe_4P_4 skeleton.[2] In the case of $Cp^R = C_5H_2tBu_3\text{-}1,2,4$ the complex $[\{Cp^R(OC)_2Fe\}_2(\mu\text{-}\eta^1:\eta^1\text{-}P_4)]$, a molecule with a P_4 butterfly framework was synthesized.[3] Finally, the use of $Cp^R = C_5Me_5$ gave for the first time $[Cp^*Fe(\eta^5\text{-}P_5)]$, a sandwich complex with a *cyclo*-P_5^- ligand, the all-phosphorus analogue of the cyclopentadienide ion $C_5H_5^-$.[4]

The photochemical route, realized for $Cp^R = C_5H_4Me$ or $C_5H_3tBu_2\text{-}1,3$ (Cp''), affords $[Cp^R{}_4Fe_4(CO)_6P_8]$ with an open-edged P_8 cuneane geometry[5] and all five members of the series $[Cp''_2Fe_2P_4(CO)_{4-n}]$ ($n = 0\text{–}4$) with different P_4 ligands.[6]

The experiences of the last decade have shown that especially highly alkylated Cp^R ligands are very useful in the coordinative stabilization of different P_n ligands. Interestingly, to the best of our knowledge, until now transition-metal complexes with trimethylsilyl-substituted Cp^R ligands are unknown as starting materials in P_n chemistry.

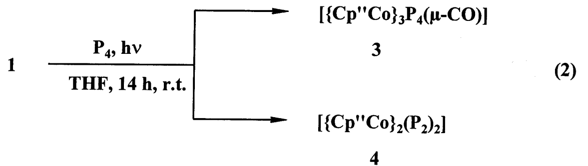
Thermal and Photochemical Reaction of $[Cp''Co(CO)_2]$ [1, $Cp'' = C_5H_3(SiMe_3)_2\text{-}1,3$] with White Phosphorus (P_4)

According to Equation 1 the cothermolysis of $[Cp''Co(CO)_2]$ (**1**) and P_4 (Co/P ≈ 1:7) affords exclusively the tetranuclear cobalt complex **2** with a P_{10} ligand in the unusually high yield of 87%.

$$\underset{\mathbf{1}}{[Cp''Co(CO)_2]} \xrightarrow[\text{72 h, ca. 140 °C}]{P_4,\ \text{xylene}} \underset{\mathbf{2}}{[\{Cp''Co\}_2(P_5\text{-}P_5)\{CoCp''\}_2]} \qquad (1)$$

$Cp'' = C_5H_3(SiMe_3)_2\text{-}1,3$

For a stoichiometry of Co/P ≈ 1:2 the photochemical alternative gives 30 % of **3** and 10 % of **4** (Equation 2) besides traces of **2**.



$Cp'' = C_5H_3(SiMe_3)_2\text{-}1,3$

The air-sensitive olive-green (**2**), dark-red (**3**), or black-purple (**4**) complexes are sparingly to well soluble in *n*-hexane and dissolve readily in toluene or dichloromethane.

NMR- and IR-Spectroscopic Investigations

The ^1H-, ^{31}P-NMR data of the complexes **2**, **3**, and **4** as well as $\tilde{\nu}(CO)$ of **3** are compiled in Table 1.

The ^1H-NMR spectrum of **2** (measured at 340 K) affords 11 signals with relative integrals 2:2:2:2:2:1:1:18:18:18:18 in agreement with a local symmetric environment for each Cp'' ligand. In the ^{31}P-NMR spectrum of **2** (340 K) the P_{10} skeleton (Figure 1) consists of an ABCC′DD′EE′FF′ spin system. A comparison of the $^1J(P_AP_B)$ coupling constants of the P_2 bridge in **2** (−205 Hz) and **5** (−95 Hz)[7] suggests deviation of the lone pairs in the "bridge" P1−P1′ from an antiperiplanar position for complex **2**.

The Schakal plot shows that each $C_5H_3(SiMe_3)_2\text{-}1,3$ ligand of **2** is locked between two adjacent ligands.

Comparing the spectroscopic data of **3** and **7**[8] the following discrepancies were found: In contrast to the "remarkable high-field shift" discussed for **7**[8] ($\delta = -398.6$) for the P atom surrounded by three cobalt atoms, a value of $\delta = 487.8$ (Table 1) was measured for **3**. A redetermination of the ^{31}P-NMR spectrum of **7** gives instead of the

---

[+] Crystal-structure analyses.

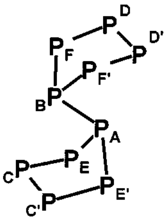
[a] Fachbereich Chemie der Universität Kaiserslautern,
Erwin-Schrödinger-Straße, D-67663 Kaiserslautern, Germany

1434−1948/99/0606−0945 $ 17.50+.50/0

Table 1. ^{1}H-, ^{31}P-NMR, and ṽ(CO) data of the complexes **2**, **3**, and **4**

Cp'' = $C_5H_3(SiMe_3)_2$-1,3	[{Cp''Co}$_4$P$_{10}$] (**2**)	[{Cp''Co}$_3$P$_4$(CO)] (**3**)	[{Cp''Co}$_2$(P$_2$)$_2$] (**4**)
^{1}H NMR[a] δ [ppm]	5.66 (s, 2 H) 5.52 (s, 2 H) 5.17 (s, 2 H) 5.02 (s, 2 H) 4.90 (s, 2 H) 4.68 (s, 1 H) 4.66 (s, 1 H) 0.70 (s, 18 H) 0.68 (s, 18 H) 0.36 (s, 18 H) 0.35 (s, 18 H)	5.89 (s, br, 2 H) 5.77 (s, br, 1 H) 5.05 (s, br, 6 H) 0.49 (s, 18 H) 0.45 (s, 18 H) 0.32 (s, 18 H)	4.54 (s, br, 4 H) 4.36 (s, br, 2 H) 0.47 (s, 36 H)
Spin system	ABCC′DD′EE′FF′	AM$_2$X	A$_4$
^{31}P NMR[b] δ [ppm]	269.6 (m, 1 P, P$_A$) 268.7 (m, 1 P, P$_B$) 74.4 (pdd, 2 P, P$_C$) 70.7 (pdd, 2 P, P$_D$) −137.2 (m, 2 P, P$_E$) −139.6 (m, 2 P, P$_F$)	487.8 (t, 1 P, P$_A$) 239.7 (dd, 2 P, P$_M$) 22.0 (t, 1 P, P$_X$)	−36.3 (s)
^nJ [Hz]	$^1J_{AB} = -205$, $^1J_{AE} = -311$ $^2J_{AD} = 33$ $^1J_{BF} = -307$, $^2J_{BC} = 6$ $^1J_{CE} = -359$, $^2J_{CC'} = 79$ $^1J_{DF} = -358$, $^2J_{DD'} = 75$ $^2J_{CE'} = 34$, $^2J_{DF'} = 46$	$J_{AM} = 43$ $^1J_{MX} = -364$	
ṽ(CO) [cm^{-1}][c]		1808 (s)	

[a] 400 MHz: **2**: 340 K; **3/4**: 298 K. – [b] 162 MHz: **2**: 340 K; **3/4**: 298 K (C_6D_6, 85% H_3PO_4 ext.). – [c] 298 K, THF.



[{Cp''Co}$_2$(P$_5$-P$_5$){CoCp''}$_2$] (2)

ABCC'DD'EE'FF'-spin system

Figure 1. Spin system of complex **2**

[{Cp'''Co}$_2$(P$_5$-P$_3$){CoCp'''}]

5

Cp''' = $C_5H_2Bu^t_3$-1,2,4

[{Cp''Rh}$_2$(P$_5$-P$_5$){RhCp''}$_2$]

6

Cp'' = $C_5H_3Bu^t_2$-1,3

reported[8] δ = −398.6 the expected low-field shift (δ = 413.8). The other ^{31}P-NMR signals (**7**: δ = 227.5, 9.9) are in agreement with the published data.[8] Going from **7** to **3** all ^{31}P-NMR signals are shifted down-field in the bis(trimethylsilyl)cyclopentadienyl derivative **3** (cf. Table 1).

[{Cp''Co}$_3$P$_4$(μ-CO)]

7

Cp'' = $C_5H_3Bu^t_2$-1,3

The redetermination of ṽ(CO) in **7** gives 1793 cm^{-1} instead of the published 1934 cm^{-1}.[8] This value is in accordance with 1808 cm^{-1} measured for **3**. Both bands are in the region expected for a μ-CO ligand (cf. Figure 5).

X-ray Crystal-Structure Determinations of the Complexes 2, 3, and 4

Compound 2

The most interesting structural aspect of complex **2** is its Co$_4$P$_{10}$ skeleton (Figure 2).

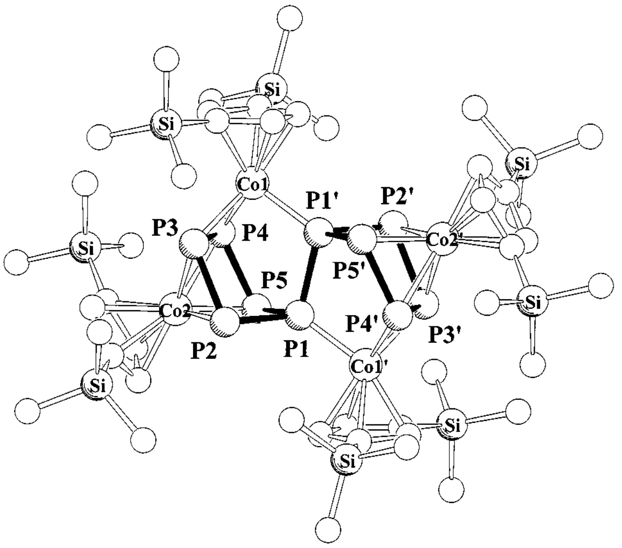
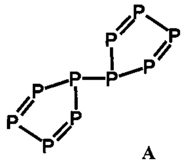


Figure 2. Selected bond lengths [Å] and angles [°]: P1−P1′ 2.1793(18), P2−P1 2.1948(14), P2−P3 2.1573(14), P3−P4 2.4743(15), P4−P5 2.1573(14), P5−P1 2.1985(14), Co1−P1′ 2.1311(11), Co1−P3 2.2405(11), Co1−P4 2.2446(11), Co2−P2 2.3108(12), Co2−P5 2.3196(12), Co2−P3 2.3355(11), Co2−P4 2.3753(11), Co1−Cp′′(centr.) 1.72, Co2−Cp′′(centr.) 1.72; P1′−Co1−P3 93.95(4), P1′−Co1−P4 93.44(4), P3−Co1−P4 66.96(4), Co1−P1′−P1 111.43(6), P2−P1−P1′ 100.11(7), P2−P1−P5 90.82(5), P5−P1−P1′ 101.18(6)

The P_{10} framework can be derived formally from the P_{10} dihydrofulvalene **A** (Figure 3) where the two 4π systems bind to Co2(2′) giving 18e⁻ per cobalt atom. This electron count can also be obtained for Co1(1′) taking into account the lone pair on P1(1′) and the bond(s) P3(3′)−P4(4′) (2.47 Å, Figure 2) which is reasonably close to the longest known 2c2e⁻-P−P bonds. For the side-on coordinated white phosphorus (P_4) in $[(Ph_3P)_2Rh(Cl)(\eta^2\text{-}P_4)]$ this edge is elongated from 2.21 Å (P_4 itself) to 2.46 Å.[9] Interestingly, for the analogous Rh_4P_{10} compound **6** a distinctly longer P···P bond (open edged) of 2.62 Å was found.[10] All the other P−P bond lengths of the P_{10} ligand in the complexes **2** and **6** are comparable [two shorter P2−P3, P4−P5: 2.16/2.15 Å (**2**/**6**); two longer: 2.20/2.19 Å (**2**/**6**)].



A

Figure 3. Hypothetic P_{10} dihydrofulvalem

Alternatively, the Co_4P_{10} framework of **2** can also be derived from Li_3P_7 (Figure 4, **B**), a well-known molecule in polyphosphide chemistry.[11]

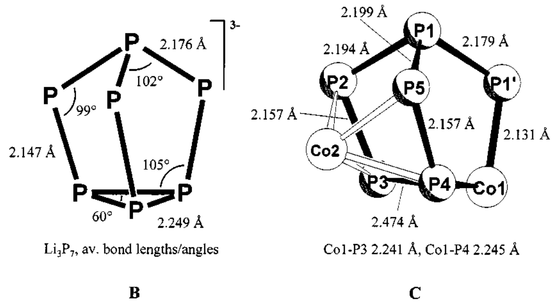


Figure 4. Comparison of P_7^{3-} with the Co_2P_6 cage of **2**

Formally, **C** (Figure 4) can be derived from **B** by replacing one basal P atom by the Co1Cp″ fragment and capping the four-electron donor P2,3,4,5 unit by the Co2Cp″ unit. Electron count and *d*(P1′−Co1) are in favour of a multiple-bond character.

The connection of two Co_2P_6 subunits **C** with a common edge (P1−P1′) formally gives the Co_4P_{10} skeleton of compound **2** (Figure 2). The biggest difference in bond lengths between **B** and **C** occurs, as one would expect, in the basal triangle P3,P4,Co1 (P3−P4 2.47 Å).

A further interesting parallel is realized with complexes **8**,[12] synthesized by Eichhorn's group.

$$[(\eta^4\text{-}P_7)\{M(CO)_3\}]^{3-},\quad M = Cr, Mo, W$$

8

Its carbonylation affords $[(\eta^2\text{-}P_7)W(CO)_4]^{3-}$ (**9**) where the norbornadiene-type geometry of the P_7 ligand in **8** has changed to the nortricyclane-like structure of **9** ($\eta^4 \rightarrow \eta^2$-$P_7$).[12b]

The polycyclic P_{10} core of the paramagnetic complex $[\{Cp(CO)_2Cr\}_5P_{10}]$ (**10**) consists of a P_7 norbornane with a P_2 bridge and a terminal P atom.[13]

Compound 3

Bond lengths and angles of the trinuclear cobalt complex **3** (Figure 5) differ only slightly from the values of the analogous complex **7** with $C_5H_3t\text{Bu}_2$-1,3 ligands.[8]

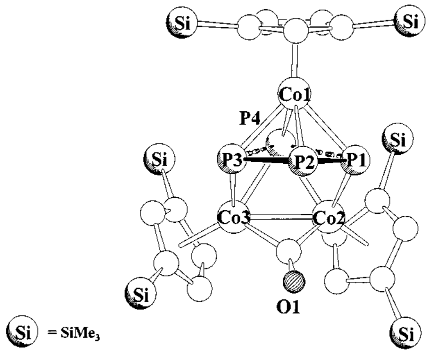


Figure 5. Selected bond lengths [Å] and angles [°]: P1−P2 2.1609(10), P2−P3 2.1585(9), P3···P4 2.5237(9), P4···P1 2.4879(8), Co2−Co3 2.4485(5), Co1−P1 2.3099(6), Co1−P2 2.2706(7), Co1−P3 2.3207(7), Co1−P4 2.2711(7), Co2−P1 2.2714(7), Co2−P4 2.2483(6), Co3−P3 2.2787(7), Co3−P4 2.2290(7), Co1−Cp″(centr.) 1.73, Co2−Cp″(centr.) 1.75, Co3−Cp″(centr.) 1.74, P1−P4−P3 78.93(3), P2−P1−P4 93.02(3), P2−P3−P4 92.09(3), P3−P2−P1 95.03(4), Co2−P4−Co3 66.30(2)

A small kite-like distortion of a *cyclo*-P_4 ligand was realized for the first time in $[\{Cp^*(OC)_2Nb\}(\eta^4\text{-}P_4)]$ (**11**), Cp″ = $C_5H_3t\text{Bu}_2$-1,3.[14] Interestingly, a much stronger distortion was found for **3** and **7**. For both complexes the P···P bonds to P4 coordinating to three $CoCp^R$ fragments are distinctly longer [average of **3**: 2.50; **7**: 2.503(2) Å]. EHT calculations on **7** are in agreement with a weak P···P bonding[8] {c.f. the 2c1e⁻ P···P bond length of 2.634(3) Å in the P_4 rectangle of the diradical $[R_2N{-}CP_2]_2^{\bullet\bullet}$ (R = *i*Pr)[15]}.

In contrast to the planar P_4 ligand of **7** the P4 atom in **3** lies 0.34 Å above the P1,P2,P3 plane (Figure 5). The missing mirror plane in compound **3** leads to small differences in bond lengths and angles relative to those in **7** (the mean values of both compounds are nearly identical).

According to the electron-counting rules[16] of Wade and Mingos complex **3** belongs to an *arachno* cluster with (n + 3) = 10 SEPs (skeleton electron pairs). Its framework can formally be derived from a *closo* tricapped trigonal prism by successive elimination of two vertices.

Compound 4

The bond lengths and angles of complex **4** (Figure 6) are very similar to those of the X-ray-crystallographically characterized derivatives $[\{Cp^*Co\}_2(\mu\text{-}\eta^2{:}\eta^2\text{-}P_2)_2]$ (**12**)[17] and $[\{Cp'''Co\}_2(\mu\text{-}\eta^2{:}\eta^2\text{-}P_2)]$ (**13**) (Cp‴ = $C_5H_2t\text{Bu}_3$-1,2,4).[18]

For the side-on coordinated 4e⁻ donor P_2, which is isoelectronic and isolobal with acetylene (|P≡P| $\underset{\smile}{\longrightarrow}$

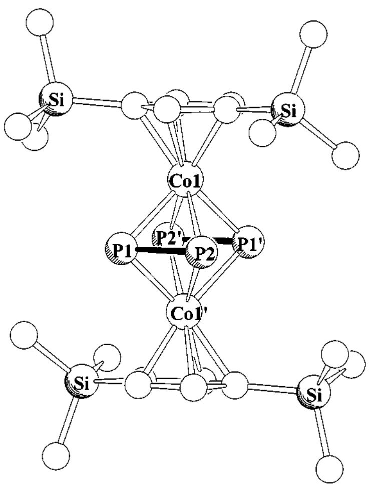


Figure 6. Selected bond lengths [Å] and angles [°]: P1−P2 2.0538(15), P1···P2′ 2.7131(14), Co1−P1 2.3069(10), Co1−P1′ 2.3162(10), Co1−P2 2.3050(10), Co1−P2′ 2.3164(10), Co1−Cp′′-(centr.) 1.70, Co1···Co1′ 3.127; P1−P2−P1′ 90.04(4), P2−P1−P2′ 89.96(4)

HC≡CH), *d*(P−P) lies in the range of 2.054 (**4**), 2.053 (**12**), and 2.052 Å (**13**) which is typical for P−P double bonds.[1] The long P···P edges of the rectangular $(P_2)_2$ ligands have nonbonding distances of 2.713, 2.705 (mean value), and 2.663 Å, *d*(Co−P) ranges from 2.311 to 2.305 and 2.308 Å, respectively. Such small differences also exist for Co···Co (3.127, Figure 6) (**12**: 3.102; **13**: 3.164 Å). For all three complexes the least-squares plane defined by the two μ-η^2:η^2-P_2 units and the planes of the two Cp^R rings differ only slightly (2°, 1°, and 2°) from a parallel arrangement.

Experimental Section

All experiments were carried out under argon in anhydrous solvents. − NMR: Bruker AMX 400, ^{1}H NMR (400.13 MHz), ^{31}P NMR (161.98 MHz). − The ^{31}P-NMR spectra of **2** was simulated with PERCH.[20] IR spectra were recorded with an FT-IR spectrometer Perkin−Elmer 16 PC. − UV irradiation: 150-W Hg high-pressure lamp, TQ 150, Heraeus Quarzlampen GmbH, Hanau. − [Cp′′Co(CO)$_2$] (**1**) [Cp′′ = $C_5H_3(SiMe_3)_2$] was synthesized from [$Co_2(CO)_8$] and Cp′′H in analogy to ref.[19]

Cothermolysis of [Cp′′Co(CO)$_2$] (1) and White Phosphorus (P_4): 1.72 g (5.3 mmol) of **1** and 1.2 g (9.7 mmol) of P_4 were heated to reflux in 50 mL of xylene for 72 h. After evaporation of the solvent under oil-pump vacuum (0 → 35 °C), the residue was dissolved in ca. 20 mL of dichloromethane, and ca. 5 g of neutral Al_2O_3 (activity grade II) was added. The solvent was evaporated under oil-pump vacuum from the mixture until the residue was free-flowing. It was placed on top of a column (2 × 15 cm) filled with neutral Al_2O_3 and petroleum ether. A mixture of petroleum ether/diethyl ether (40:1) eluted [{Cp′′Co}$_2$(P_5−P_5){CoCp′′}$_2$] (**2**); yield 1.7 g (87 %) of olive-green crystals. − $C_{50}H_{98}Co_4P_{10}Si_8$ (1469.4): calcd. C 40.86, H 6.72; found C 40.34; H 6.77.

Cophotolysis of 1 and P_4: 1.13 g (3.5 mmol) of **1** and 0.19 g (1.5 mmol) of P_4 were irradiated (150-W Hg high-pressure lamp) for 14 h in 100 mL tetrahydrofuran until the $\tilde{\nu}$(CO) bands of **1** had disappeared and a new one at 1808 cm^{-1} had emerged. Column chromatography as described for complex **2** gave with the same mixture of solvents as first fraction 115 mg (10 %) of purple [{Cp′′Co}$_2$(P_2)$_2$] (**4**) followed by 330 mg (30 %) of red-brown [{Cp′′Co}$_3$$P_4$(CO)] (**3**). − **3**: $C_{34}H_{63}Co_3OP_4Si_6$ (957.1): calcd. C 42.66, H 6.63; found C 40.05, H 6.65. − **4**: $C_{22}H_{42}Co_2P_4Si_4$ (660.7): calcd. C 39.99, H 6.41; found C 27.19 (incomplete combustion), H 5.87.

Single-Crystal X-ray Structure Determination: See also Table 2. Crystallographic data (excluding structure factors) for the struc-

Table **2**. Crystallographic data for complexes **2**, **3**, and **4**[a]

Cp′′ = $C_5H_3(SiMe_3)_2$-1,3	[{Cp′′Co}$_4$$P_{10}$] (**2**)	[{Cp′′Co}$_3$$P_4$(CO)] (**3**)	[{Cp′′Co}$_2$(P_2)$_2$] (**4**)
formula	$C_{50}H_{98}Co_4P_{10}Si_8$	$C_{34}H_{63}Co_3OP_4Si_6$	$C_{22}H_{42}Co_2P_4Si_4$
M_r	1469.4	957.1	660.7
crystal size [mm]	0.51 × 0.30 × 0.22	0.40 × 0.20 × 0.12	0.64 × 0.29 × 0.14
crystal system	triclinic	monoclinic	triclinic
space group	$P\bar{1}$	$P2_1/n$	$P\bar{1}$
a [Å]	10.9820(10)	17.7233(15)	6.5930(10)
b [Å]	14.117(2)	12.3106(6)	11.297(2)
c [Å]	14.6760(10)	23.9381(18)	11.981(3)
α [°]	109.180(10)	90	79.42(2)
β [°]	102.050(10)	111.286(9)	79.08(2)
γ [°]	109.890(10)	90	78.95(2)
V [Å^3]	1884.6(3)	4866.6(6)	849.9(3)
Z	1	4	1
T [K]	293	293	293
$d_{calcd.}$ [g cm^{-3}]	1.295	1.306	1.291
μ [mm^{-1}]	1.234	1.314	1.315
2Θ range [°]	2.05−25.00	2.43−27.50	2.74−27.50
measured refl.	7676	60076	4905
independent refl.	6341	11105	3897
refined parameters	339	451	152
$R1$ ($I \geq 2\sigma I$)	0.0410	0.0285	0.0409
$wR2$ (all data)	0.0997	0.0538	0.1144
residual electron density [e·Å^{-3}]	0.519/−0.255	0.318/−0.235	0.619/−0.514
diffractometer	Siemens P4	Stoe IPDS	Siemens P4

[a] Structure solution by Direct Methods SHELXL-97, SIR 92; refinement: full-matrix least-squares methods against F^2.

tures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-115135 (**2**), -115137 (**3**), -115136 (**4**). Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: int. code + 44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

Acknowledgments

This work was supported by the Fonds der Chemischen Industrie and the Graduiertenkolleg: "Phosphorus Chemistry as a Link between Different Chemical Disciplines".

---

[1] O. J. Scherer, *Angew. Chem.* **1990**, *102*, 1137−1155; *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 1104−1122.

[2] O. J. Scherer, G. Kemény, G. Wolmershäuser, *Chem. Ber.* **1995**, *128*, 1145−1148.

[3] O. J. Scherer, T. Hilt, G. Wolmershäuser, *Organometallics* **1998**, *17*, 4110−4112.

[4] O. J. Scherer, T. Brück, *Angew. Chem.* **1987**, *99*, 59; *Angew. Chem. Int. Ed. Engl.* **1987**, *26*, 59.

[5] M. E. Barr, B. R. Adams, R. R. Weller, L. F. Dahl, *J. Am. Chem. Soc.* **1991**, *113*, 3052−3060.

[6] O. J. Scherer, G. Schwarz, G. Wolmershäuser, *Z. Anorg. Allg. Chem.* **1996**, *622*, 951−957.

[7] O. J. Scherer, G. Berg, G. Wolmershäuser, *Chem. Ber.* **1996**, *129*, 53−58.

[8] M. Scheer, U. Becker, M. H. Chisholm, J. C. Huffman, F. Lemoigno, O. Eisenstein, *Inorg. Chem.* **1995**, *34*, 3117−3119.

[9] A. P. Ginsberg, W. E. Lindsell, K. J. McCullough, C. R. Sprinkle, A. J. Welch, *J. Am. Chem. Soc.* **1986**, *108*, 403−416.

[10] O. J. Scherer, B. Höbel, G. Wolmershäuser, Angew. Chem. **1992**, *104*, 1042−1043; *Angew. Chem. Int. Ed. Engl.* **1992**, *31*, 1027−1028.

[11] Reviews: H.-G. von Schnering, W. Hönle, *Chem. Rev.* **1988**, *88*, 243−273; M. Baudler, K. Glinka, *Chem. Rev.* **1993**, *93*, 1623−1667; **1994**, *94*, 1273−1297.

[12] [12a] S. Charles, B. W. Eichhorn, A. L. Rheingold, S. G. Bott; *J. Am. Chem. Soc.* **1994**, *116*, 8077−8086. − [12b] S. Charles, J. C. Fettinger, B. W. Eichhorn, *Inorg. Chem.* **1996**, *35*, 1540−1548.

[13] L. Y. Goh, R. C. S. Wong, E. Sinn, *J. Chem. Soc., Chem. Commun.* **1990**, 1484−1485; L. Y. Goh, R. C. S. Wong, E. Sinn, *Organometallics* **1993**, *12*, 888−894.

[14] O. J. Scherer, J. Vondung, G. Wolmershäuser, *Angew. Chem.* **1989**, *101*, 1395−1397; *Angew. Chem. Int. Ed. Engl.* **1989**, *28*, 1355−1357.

[15] Y. Canac, D. Bourissou, A. Baceiredo, H. Gornitzka, W. W. Schoeller, G. Bertrand, *Science* **1998**, *279*, 2080−2082.

[16] K. Wade, *Adv. Inorg. Chem. Radiochem.* **1976**, *18*, 1−66; D. M. P. Mingos, R. L. Johnston, *Struct. Bond.* **1987**, *68*, 29−87.

[17] M. E. Barr, L. F. Dahl, *Organometallics* **1991**, *10*, 3991−3996.

[18] O. J. Scherer, G. Berg, G. Wolmershäuser, *Chem. Ber.* **1995**, *128*, 635−639.

[19] S. A. Frith, J. L. Spencer, *Inorg. Synth.* **1985**, *23*, 15−21.

[20] R. Laatikainen, M. Niemitz, J. Sundelin, T. Hassinen, Program package *PERCH*, version 1/96, University of Kuopio, Finland, **1996**.

Received December 28, 1998
[I98452]