

Desulfurization Reaction of *cis*-1,2-Diphenyl-3-aryl-1,4,2-diazaphospholidin-5-thione-2-oxides Utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ or ROH System

Jia Zhou and Ruyu Chen

Institute of Elemento-Organic Chemistry, National Key Laboratory of Elemento-Organic Chemistry, Nankai University, Tianjin 300071, People's Republic of China

Received 20 September 1997; revised 26 February 1998

ABSTRACT: A desulfurization reaction of the title compounds, as cyclic substrates, utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ or ROH system, is described in this article. The diastereoisomerism of ring-opening products and the possible reaction mechanism are also discussed. The molecular structure of α -(3-phenylureido)- α -(2,4-dichlorophenyl)methylphenylphosphinic acid (**4a**) was determined by X-ray diffraction. © 1998 John Wiley & Sons, Inc. Heteroatom Chem 9: 585–590, 1998

INTRODUCTION

Efficient methodologies for transforming a carbonyl into a thiocarbonyl functionality are available in the arsenal of the synthetic chemist [1]. However, for the reverse conversion, there is a lack of general and efficient methods. The different reagents used so far to effect this conversion meet with varying degrees of success and are inconvenient, as they employ the use of stoichiometric amounts of oxidants or harsh conditions [2]. Although numerous approaches about oxidizing the sulfur of some straight-chain thiourea derivatives have been disclosed in the literature [3–6], that of cyclic phosphoryl thiourea derivatives utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ or ROH system has up to now not been reported.

Previously, we reported the synthesis of some *cis*-1,4,2-diazaphospholidin-5-thione-2-oxides and their highly selective herbicidal activity [7,8]. In this article, the desulfurization of the title compounds, as cyclic substrates, under mild conditions utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ or ROH system is reported for the first time. The diastereoisomerism of the ring-opened products and the possible reaction mechanism are also described herein. Significantly, the desulfurization with the reaction systems previously mentioned has flexibility to some degree and can be extended to various kinds of cyclic thiourea substrates.

RESULTS AND DISCUSSION

Desulfurization Reaction of the Title Compounds Utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ System

We have shown previously that desulfurization of open-chain phosphoryl thiourea derivatives with an $\text{Ag}^+ - \text{H}_2\text{O}$ system gives the corresponding urea derivatives [9]. This work is extended to the desulfurization of the cyclic phosphoryl thiourea derivatives (*cis*-1). However, these reactions do not give the expected cyclic phosphoryl ureas (*cis*-2); instead, they result in the formation of ring-opening products (Scheme 1). The physical and chemical data obtained for the isolated products (see Tables 1 through 3) did not provide full evidence of their structures and whether P–N bond cleavage (path c leading to 4) or C–N bond cleavage (path b leading to 3) occurred [10]. The molecular structure of the product was determined by single-crystal X-ray diffraction

Correspondence to: Jia Zhou.

The research was supported by the National Natural Science Foundation of China.

© 1998 John Wiley & Sons, Inc. CCC 1042-7163/98/060585-06

TABLE 1 Experimental Data of Compounds 4a–b and 7a–d

NO	R	R ¹	Yield (%)	MP (°C)	Molecular Formula	Calcd/Found (%)		
						C	H	N
4a	2,4-Cl ₂	—	88.7	208–210	C ₂₀ H ₁₇ Cl ₂ N ₂ O ₃ P (435.3)	55.18	3.94	6.44
						55.33	4.06	6.40
4b	o-OMe	—	91.7	214–215	C ₂₁ H ₂₁ N ₂ O ₄ P (396.4)	63.63	5.35	7.07
						63.57	5.52	7.23
7a	2,4-Cl ₂	Me	87.4	200–201	C ₂₁ H ₁₉ Cl ₂ N ₂ O ₃ P (449.3)	56.13	4.27	6.24
						56.24	4.56	6.41
7b	p-OPh	Et	92.2	86–88	C ₂₈ H ₂₇ N ₂ O ₄ P (486.5)	69.12	5.61	5.76
						69.24	5.57	5.77
7c	2,4-Cl ₂	Et	94.0	114–116	C ₂₂ H ₂₁ Cl ₂ N ₂ O ₃ P (463.3)	57.03	4.58	6.05
						57.07	4.66	6.41
7d	o-OMe	Me	90.2	215–216	C ₂₂ H ₂₃ N ₂ O ₄ P (410.4)	64.38	5.66	6.83
						64.18	5.75	6.90

TABLE 2 Spectroscopic Data of Compounds 4a–b and 7a–d

Compound	IR (KBr pellet) ν (cm ⁻¹)	¹ H-NMR (DMSO-d ₆ , TMS) ^a δ, J (Hz)	³¹ P-NMR (δ) ^b (Ratio of Diastereoisomers)
4a	3312 (s, NH), 3192, 3080, 2942, 1642 (s, C = O), 1606, 1553, 1514, 1467, 1437, 1256 (m, P = O), 1172, 1121, 1096, 930 (s, C-N), 869 (m), 832 (m), 750 (s), 698 (s)	5.4–5.6 (d, 1H, CH), 6.85 (m, 1H, NH), 7.08–8.0 (m, 14H, 2Ph, C ₆ H ₃ and NH)	27.86
4b	3399 (s, NH), 3191, 2947, 1636 (s, C = O), 1597, 1551, 1507, 1459, 1437, 1250 (s, P = O), 1180, 1129, 1089, 1023, 943 (s, C-N), 747 (s), 719, 689 (m)	3.49 (s, 3H, OCH ₃), 5.63 (d, 1H, CH), 6.70–7.63 (m, 16H, 2Ph, C ₆ H ₄ and 2NH)	30.96
7a	3327 (s, NH), 3133, 2935, 1697 (s, C = O), 1598, 1548, 1497, 1439, 1194 (s, P = O), 1150, 1116, 1040, 998 (s, C-N, P-O-C), 869, 799 (m), 778, 690 (s)	3.50–3.86 (dd, 3H, OCH ₃ , ³ J _{PH} = 10.8), 6.28 (dd, 1H, CH), 6.72–8.04 (m, 14H, 2Ph, C ₆ H ₃ and NH), 8.32 (br, 1H, NH)	36.48, 35.54 (5.03:1)
7b	3320 (s, NH), 3076, 2911, 1699 (s, C = O), 1595, 1543, 1495, 1438, 1192 (s, P = O), 1115, 1026, 951 (s, C-N, P-O-C), 745, 704 (s)	1.17–1.42 (dt, 3H, CH ₃), 3.87–4.25 (m, 2H, CH ₂), 5.75 (dd, 1H, CH, J = 8.33), 6.71–8.02 (m, 20H, 3Ph, C ₆ H ₄ and NH), 8.54–8.71 (ds, 1H, NH)	41.16, 39.64 (1:4)
7c	3327 (s, NH), 3196, 3078, 2910, 1697 (s, C = O), 1599, 1546, 1466, 1438, 1191 (s, P = O), 1116, 1095, 1074, 1016, 960 (s, C-N, P-O-C), 868, 806 (m), 746, 709 (s)	1.13–1.36 (dt, 3H, CH ₃), 3.80–4.27 (m, 2H, CH ₂), 6.30 (dd, 1H, CH, J = 8.33), 6.86–8.02 (m, 14H, 2Ph, C ₆ H ₃ and NH), 8.42–8.59 (ds, 1H, NH)	34.59, 26.65 (8.94:1)
7d	3386 (s, NH), 3100, 2949, 1690 (s, C = O), 1590, 1556, 1494, 1436, 1196 (s, P = O), 1115, 1052, 1028, 957 (s, C-N, P-O-C), 749 (s), 720, 688 (s)	3.24–3.44 (dd, 3H, OCH ₃ , ³ J _{PH} = 10.8), 3.78–3.88 (ds, 3H, OCH ₃), 6.30 (dd, 1H, CH), 6.68–8.04 (m, 15H, 2Ph, C ₆ H ₄ and NH), 8.56–8.70 (ds, 1H, NH)	42.13, 40.52 (1:1.5)

¹H-NMR spectra of 4a, 7a–b, and 7d were recorded at 90 MHz with a JEOL-FX-90Q spectrometer, others, at 200 MHz with a BRUKER AC-P200 spectrometer.

³¹P-NMR spectrum of 7b was recorded at 80.96 MHz with a BRUKER AC-P200 spectrometer, others, at 36.19 MHz with a JEOL-FX-90Q spectrometer.

TABLE 3 EI-MS Data of Some of Compounds **4** and **7**

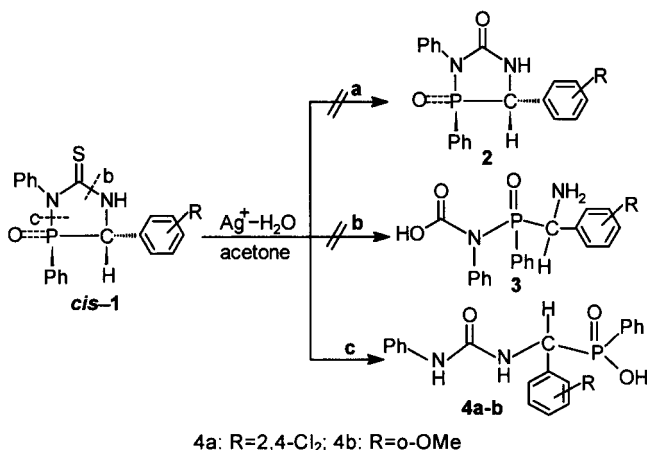
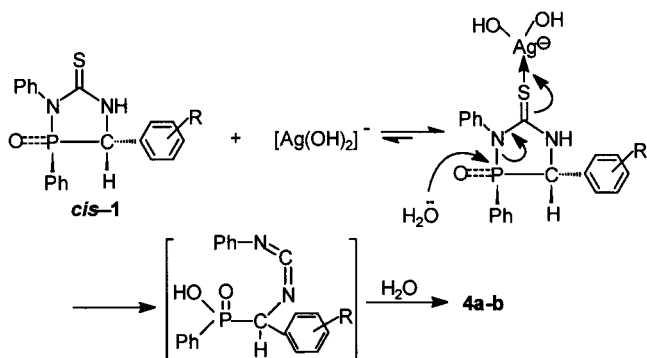
Compound	EI-MS (<i>m/z</i> , %)
4a	417 (M ⁺ -OH, 1.0), 416 (M ⁺ -H ₂ O, 4.0), 174 (8.5), 159 (18.5), 119 (81.8), 93 (100), 77 (36.2), 64 (18.0)
7a	448 (M ⁺ , 2.5), 295 (24.4), 293 (36.9), 235 (3.5), 202 (6.3), 178 (10.6), 174 (100), 155 (32.3), 141 (10.7), 119 (11.0), 93 (28.4), 77 (47.1), 51 (13.3)
7d	410 (M ⁺ , 0.5), 255 (47.5), 212 (2.0), 162 (7.8), 155 (6.4), 136 (74.5), 119 (22.3), 107 (7.7), 104 (5.9), 93 (21.3), 91 (19.5), 77 (24.4), 65 (7.4), 46 (100), 30 (21.3)

TABLE 4 Important Molecular Parameters of Compound **4a**

Bond	Length (Å) ^a	Bond	Length (Å)	Bond	Angle (°)	Bond	Angle (°)
P-O(1)	1.531(7)	O(1)-H	0.915	O(1)-P-O(2)	115.5(4)	O(2)-P-C(20)	108.6(4)
P-O(2)	1.472(7)	N(1)-H	1.046	O(1)-P-C(11)	106.4(4)	C(11)-P-C(20)	112.1(4)
P-C(11)	1.752(9)	N(2)-H	0.971	O(1)-P-C(20)	105.3(4)	P-C(20)-N(1)	105.5(5)
P-C(20)	1.843(8)	O(3) ⋯ H(2d) ^b	1.886	O(2)-P-C(11)	109.0(4)	O(3) ⋯ H(2d)-N(2d)	167.7

^aNumbers in parentheses are estimated standard deviations in the least significant digits.

^bSymmetry operations: *d*: 1.5 - *x*, *y*, 0.5 + *z*.

**SCHEME 1****SCHEME 2**

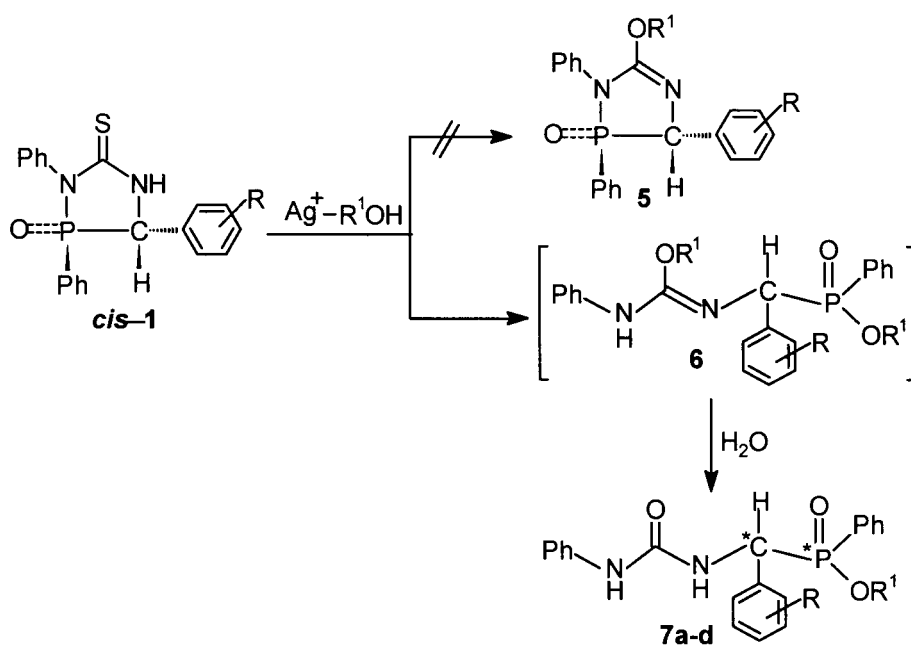
analysis as structure **4** (Figure 1 and Table 4), indicating a P-N bond cleavage. Figure 2 depicts molecular packing in the unit cell, which indicates that two adjacent molecules are symmetrically linked to each other through the intermolecular hydrogen bonding.

A possible reaction mechanism for the desulfurization of *cis*-1 by aqueous silver ions is illustrated in Scheme 2. The mechanism is similar to that proposed for the acyclic case and includes the formation of a diimide intermediate.

Desulfurization Reaction of the Title Compounds Utilizing an Ag⁺-ROH System

Oxidizing the sulfur of the open-chain phosphoryl thioureas, utilizing an Ag⁺-ROH system, regioselectively gave the imino-ether derivatives with a C=N double bond [9]. On the contrary, N³-phenyl ureidoalkanephosphonates **7a-d** were obtained (87.4–94.0%) in the desulfurization of the cyclic substrates *cis*-1 under the same reaction conditions instead of the cyclic or chain products **5** or **6** bearing a C=N moiety (Scheme 3). The reaction might occur *via* the possible intermediate **6**. However, the attempt for the isolation of **6** was confirmed to be unsuccessful by working up the reaction under nonaqueous conditions or with a minimum amount of water.

The physical and chemical data listed in Tables 1 through 3 are in good agreement with the structures of **7a-d**. The EI-MS spectra of **7a-d** demonstrate the existence of the stable molecular ion peaks. Both the ¹H NMR and ³¹P NMR spectra of **7a-d** reveal the generation of two diastereoisomers due



7a: $\text{R}=2,4\text{-Cl}_2, \text{R}'=\text{Me}$; 7b: $\text{R}=\text{p-OPh}, \text{R}'=\text{Et}$; 7c: $\text{R}=2,4\text{-Cl}_2, \text{R}'=\text{Et}$; 7d: $\text{R}=\text{o-OMe}, \text{R}'=\text{Me}$

SCHEME 3

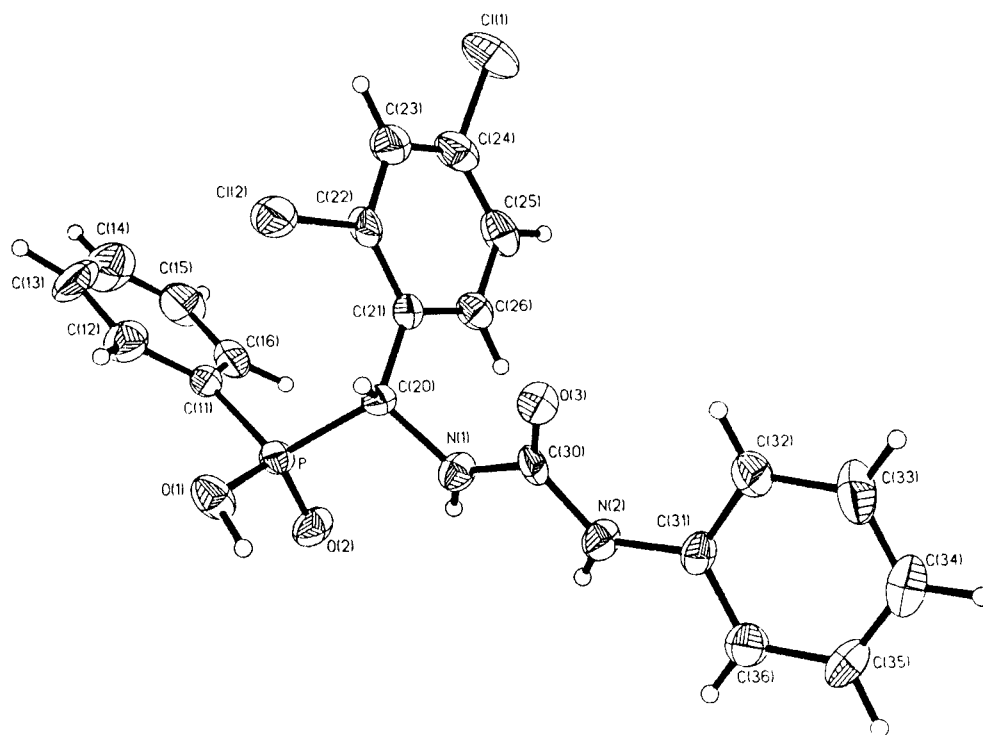


FIGURE 1 The molecular structure of compound **4a**.

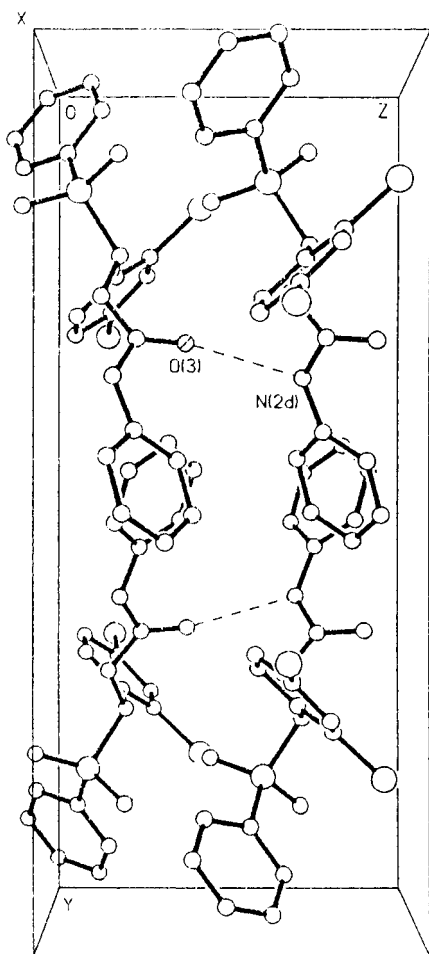


FIGURE 2 Molecular packing in the unit cell.

to the presence of two stereocenters, namely, the α -carbon atom and the chiral phosphorus. Therefore, two sets of signals are observed for alkyl and alkylene protons and ^{31}P . It is worthy of note that the case previously mentioned in the alkanephosphonates **7a–d** is different from that in the alkanephosphonic acids **4a–b**, for which tautomerism exists and only one group of signals is displayed.

EXPERIMENTAL

Instruments

NMR spectra were taken on a JEOL-FX-90Q spectrometer and BRUKER AC-P200 instrument. Tetramethylsilane (TMS) was used as an internal standard for ^1H NMR, and 85% H_3PO_4 was used as an external standard for ^{31}P NMR spectroscopy. The nuclei that are deshielded relative to their respective standards are assigned a positive chemical shift. IR spectra were recorded on a SHIMADZU-435 spectrometer. Mass spectra were recorded on a Hewlett-

Packard 5988 instrument. Elemental analyses were carried out on a Yana MT-3 instrument. Melting points were determined with a model YANACO MP-500 apparatus and are uncorrected.

Desulfurization Reaction of the Title Compounds (*cis*-1) Utilizing an $\text{Ag}^+ - \text{H}_2\text{O}$ System

General Procedure. To a vigorously stirred solution of *cis*-1 (0.8 mmol) [8] in acetone (10 mL), a solution of silver nitrate (1.6 mmol) in deionized water (4 mL) was added dropwise at ambient temperature. After having been stirred for 5 hours, the resulting mixture was filtered, and the black precipitate was discarded. Then the solvent acetone was removed under reduced pressure, and to the residue, a large amount of water was added, yielding compounds **4a–b**, which were recrystallized from a mixture of acetone and petroleum ether as colorless crystals (88.7–91.7%). The physical and chemical data are listed in Tables 1 through 3.

Desulfurization Reaction of the Title Compounds (*cis*-1) Utilizing an $\text{Ag}^+ - \text{ROH}$ System

General Procedure In each case, 0.8 mmol of *cis*-1 was allowed to react with 1.6 mmol of silver nitrate in 20 mL of anhydrous alcohol at room temperature for 8 hours, then the mixture was filtered, and, after removal of the solvent from the filtrate under reduced pressure, a large amount of water was added to the residue, yielding compounds **7a–d**, which were recrystallized from a mixture of DMF- H_2O as colorless crystals (87.4–94.0%). The physical and chemical data are also given in Tables 1 through 3.

Crystal Structure Determination of Compound **4a**

A crystal of **4a** suitable for X-ray diffraction analysis was obtained by slow crystallization from acetone. Crystal data: $\text{C}_{20}\text{H}_{17}\text{Cl}_2\text{N}_2\text{O}_3\text{P}$, $M_r = 435.25$. Orthorhombic: $a = 11.286$ (2), $b = 20.601$ (4), $c = 8.695$ (2) Å. Space group $Pca2_1$, $V = 2021$ (1) Å 3 , $Z = 4$, $D_x = 1.430$ gcm $^{-3}$, $\mu = 4.21$ cm $^{-1}$, $F(000) = 896$. Crystallographic measurements were made at room temperature using an Enraf-Nonius CAD-4 diffractometer operating in the ω - 2θ scan mode. The intensity data were collected with a θ range 2–23° using graphite monochromated $\text{MoK}\alpha$ radiation ($\lambda = 0.71073$ Å). Intensities of 2063 unique reflections were measured, 946 of which satisfied the criterion $I \geq 3\sigma(I)$

and were used in the structure solution by direct methods employing SHELXS-86 [11]. Corrections were applied for Lp but not for absorption or extinction. Positional and thermal parameters were refined by full-matrix least squares minimizing the function $\Sigma\omega(F_o - F_c)^2$ with $\omega = 1/\sigma^2(F)$ for the observed reflections and, $\omega = 0$ for unobserved reflections. Most of the nonhydrogen atoms were located from an E-map. The others were determined with successive difference Fourier syntheses. The H, H(1), and H(2) atoms were found from the difference Fourier map. The other hydrogen atoms were added theoretically. All of them were refined with fixed position parameters and thermal factors. The final refinements by the full-matrix least-squares method with anisotropic thermal parameters for nonhydrogen atoms were converged with unweighted and weighted (unit weights) agreement factors of 0.040 and 0.045, and S of 0.62. The highest peak on the final-difference Fourier map had a height of 0.24 e/Å³ [$(\Delta/\sigma)_{\max} = 0.04$]. All calculations were performed on a PDP 11/44 computer using the SDP-PLUS program sys-

tem. Some important bond lengths and angles of compound **4a** are given in Table 4.

REFERENCES

- [1] W. M. McGregor, D. C. Sherrington, *Chem. Rev.*, 1993, 199, and references cited therein.
- [2] T. Ravindranathan, S. P. Chavan, M. M. Awachat, S. V. Kelkar, *Tetrahedron Lett.*, 36(13), 1995, 2277, and references cited therein.
- [3] W. Walter, C. Rohloff, *Liebigs Ann. Chem.*, 1975, 295.
- [4] C. A. Maryanoff, R. C. Stanzione, J. N. Plampin, *Phosphorus and Sulfur*, 27, 1986, 221, and references cited therein.
- [5] D. Penn, D. P. N. Satchell, *Chemistry and Industry*, 8, 1980, 625.
- [6] Y. G. Li, X. F. Zhu, *Chin. Chem. Lett.*, 6(1), 1995, 135.
- [7] R. Y. Chen, K. S. Feng, M. R. Chen, CN 1,063,494A (1992).
- [8] H. L. Wang, J. Zhou, Y. G. Qiu, K. S. Feng, R. Y. Chen, *Phosphorus, Sulfur, and Silicon*, 104, 1995, 135.
- [9] J. Zhou, R. Y. Chen, *Phosphorus, Sulfur, and Silicon*, 118, 1996, 247.
- [10] R. Y. Chen, J. Zhou, *Chin. Chem. Lett.*, 7(6), 1996, 539.
- [11] G. M. Sheldrick, C. Kruger, R. Goddard: *SHELXS-86: Crystallographic Computing 3*, Oxford University Press, London, pp. 175–189 (1985).