Pergamon

Tetrahedron Letters 43 (2002) 9299–9302

TETRAHEDRON
LETTERS

Simple and general synthesis of new $11H$-$11\lambda^5$-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine derivatives

Graziano Baccolini,* Carla Boga, Giulia Guizzardi and Stefano Ponzano

Dipartimento di Chimica Organica 'A. Mangini', Università di Bologna, Viale Risorgimento 4, I-40136 Bologna, Italy

Received 30 September 2002; revised 17 October 2002; accepted 22 October 2002

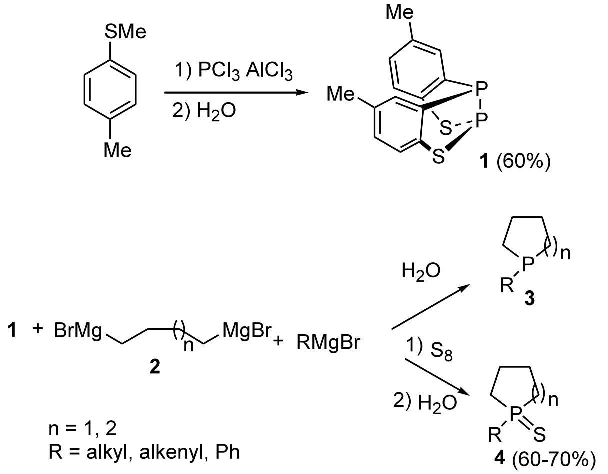
Abstract—Treatment at room temperature of benzothiadiphosphole **1** with bis-Grignard **2** gives intermediate **A**, which after 3 h gives intermediate **A′**. Subsequent addition of RMgX or sodium alcoholate and final treatment with S_8 and water affords the title compounds **5** in good yields. From the reaction mixture it is also possible to obtain the cyclic phosphine sulfide **6** or its dimeric form **7**. © 2002 Elsevier Science Ltd. All rights reserved.

The facile synthesis of heterocyclic systems containing phosphorus is of considerable current interest principally because they play a central role in coordination chemistry and homogeneous catalysis.[1] In the past we reported[2] that benzothiadiphosphole **1** is easily obtained by an unexpected domino reaction treating *p*-methylthioanisole with PCl_3 and $AlCl_3$. Compound **1** was separated by simple crystallization from reaction mixture.[2b,4b] Compound **1** is an air-stable solid, it can be stored for several years without particular precaution and it is also easy to handle. We subsequently found[3] that **1** can be used as a phosphorus donating reagent and we recently reported[4] that the simultaneous or the sequential addition of equimolar amounts of a bis-Grignard **2** ($n = 1$, 2) and a mono-Grignard RMgBr (R = alkyl, phenyl, alkenyl) to 1 equiv. of **1** gave, after addition of elemental sulfur, phosphines **3** or their sulphides **4** in good yields at room temperature (Scheme 1).

These results were explained by the intervention of hypervalent phosphorus intermediates (penta- and hexacoordinate)[5] such as **A** and **B** (Scheme 2) in which the 'dibenzo-butterfly' moiety of reagent **1**, as depicted in Scheme 1, might favour their formation. In intermediate **A** the coordination of the Mg atom with sulfur activates the P^1 atom to undergo a further nucleophilic attack.

It should be noted that the residue **C** of the reagent **1** is inferred but never isolated in the final reaction mixture. It is thus, presumably, unstable and lost by final quenching with water.

In order to obtain further information about this reaction we have now observed a new type of reactivity which occurs when the intermediate **A** is allowed to stand for about 3 h at room temperature before reacting with RMgBr. In particular, when we used RMgBr with high steric hindrance of the R group (Scheme 3) we have the prevalent formation[6] of the new heterocyclic compounds **5** (70%) with the concomitant formation of cyclic phosphine sulphide **6** (cases c, d). In contrast, when R has a smaller steric effect (cases a, b) the formation of both **5** and **4** occurs at a ratio of about 70:30.

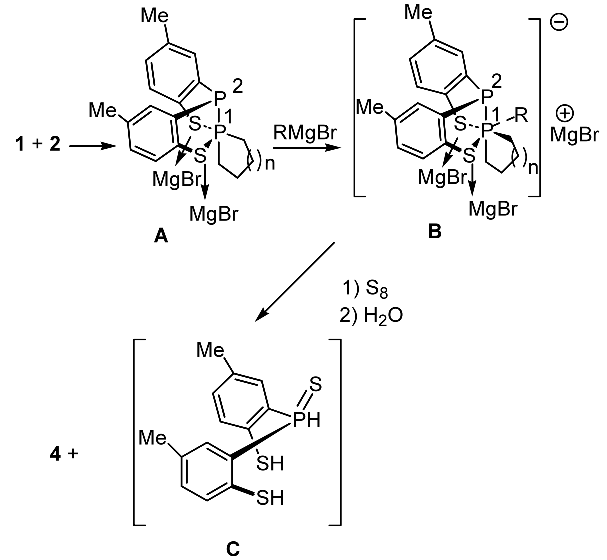


Scheme 1.

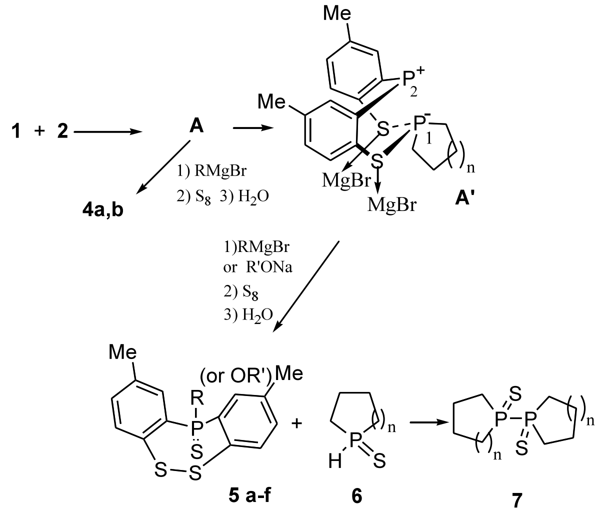
Keywords: phosphorus heterocycles; phosphine sulfides; Grignard reagents.

* Corresponding author. Tel.: +39-051-2093616; fax: +39-051-2093654; e-mail: baccolin@ms.fci.unibo.it

0040-4039/02/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0040-4039(02)02376-6



Scheme 2.



a) $R = CH(CH_3)(CH_2)_2CH_3$; b) R = Ph;
c) R = 2-Chlorophenyl; d) $R = CH(CH_3)CH{=}CH_2$;
e) $R' = CH_2CH_3$; f) $R' = CH_2CH(CH_3)CH_2CH_3$

Scheme 3.

We noticed that the ratio obtained in cases a, b depends on the time of the first step of the reaction with the formation of pentacoordinate[5] intermediate **A**. In fact, when PhMgBr is immediately added to **A** we have only **4b**, while when we added PhMgBr to **A** after leaving it to stand alone for about 3 h we found the prevalence of **5b**. This fact indicates that the pathway for the formation of **5** is more complex than the one which explains the formation of **4**.

Presumably the new intermediate might be the isomeric ionic form **A′** which can explain the inversion of reactivity of the two P atoms. In this manner, the nucleophilic attack of the second reagent can occur on the P_2 atom which is now a very reactive phosphenium ion.[7] After this attack and addition of S_8 and water, the P_1 phosphoranide,[8] an unstable hypervalent species, collapses to form compounds **5** and **6**. Tentatively this decomposition may be a reductive elimination reaction interpreted as a concerted ligand coupling process.[9]

In addition, the best yields for these dithiaphosphepines **5** are obtained when a bis-Grignard **2** with $n=2$ is used. In these cases **6** ($n=2$) is also obtained but it undergoes a rapid dimerization to the bis-phosphine sulfide **7**,[10] which has been separated and characterized. A similar conversion to a dimer of an unstable secondary phospholane was reported.[11]

We have recently reported[12] that treatment at room temperature of benzothiadiphosphole **1** with bis-Grignard **2**, sodium alcoholates and finally with S_8 affords 1-alkoxy cyclic phosphine sulfides in good yields. In a similar manner we obtained the 11-alkoxy derivatives **5e**,**f** using alcoholates as nucleophilic reagents.

It should be noted that compounds containing both phosphorus and sulphur atoms should be particularly useful to generate polydentate ligands. In addition, compounds **5** represent the first examples of a new heterocyclic system, namely 11*H*-dibenzo[*c*,*f*][1,2,5]-dithiaphosphepine 11-thione derivatives. The only related compound reported in literature[13] is the 11-phenyl-11-oxo-derivative, obtained by a two-step procedure from lithium 2-lithiobenzenethiolate at −78°C with phenylphosphonic dichloride. The 2-mercaptophenyl phosphine oxide obtained is then oxidized to cyclic disulfide by DMSO at 90°C. It is clear that with this procedure it is necessary to use various RPOCl reagents for each cyclic disulfide; these reagents are very difficult to prepare when R is not phenyl or a simple alkyl group. On the other hand, in our case it is possible to obtain compounds **5** bearing several R or OR′ groups using only different mono-Grignard reagents or sodium alcoholates in a one-pot two-step procedure carried out at room temperature. In addition, the collateral product **7** is another interesting phosphorus compound, which can be separated in 30–40% yield. It should be noted that compound **7** is reported[7] to be obtained by an anomalous and unexplained reaction in very low (6%) yield.

Finally, obtaining and being able to isolate both compounds **5** and **7** make it possible to consider our reaction as a new high atom economy process.

Acknowledgements

Investigation supported by the University of Bologna (funds for selected research topics AA 2000–2002). Thanks are also due to Consiglio Nazionale delle Ricerche (CNR, Roma) and Ministero della Ricerca Scientifica e Tecnologica (MURST) for financial support.

References

1. (a) Noyori, R. *Asymmetric Catalysis in Organic Synthesis*; Wiley: New York, 1994; (b) Burk, M. J.; Gross, M. F.; Martinez, J. P. *J. Am. Chem. Soc.* **1995**, *117*, 9375; (c) Jiang, Q.; Xiao, D.; Zhang, Z.; Cao, P.; Zang, X. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 516.
2. (a) Baccolini, G.; Mezzina, E.; Todesco, P. E.; Foresti, E. *J. Chem. Soc., Chem. Commun.* **1988**, 304; (b) Baccolini, G.; Beghelli, M.; Boga, C. *Heteroatom Chem.* **1997**, *8*, 551; (c) Gang Wu, R.; Wasylishen, E.; Power, W. P.; Baccolini, G. *Can. J. Chem.* **1992**, *72*, 1229.
3. Baccolini, G.; Orsolan, G.; Mezzina, E. *Tetrahedron Lett.* **1995**, *36*, 447.
4. (a) Baccolini, G.; Boga, C.; Negri, U. *Synlett* **2000**, 1685; (b) Baccolini, G.; Boga, C.; Buscaroli, R. A. *Eur. J. Org. Chem.* **2001**, 3421.

5. The formation of the intermediate **A** was observed by ^{31}P NMR spectroscopy as reported previously in Ref. 4b. For reviews on pentacoordinated phosphorus and similar hypervalent phosphorus compounds, see: Holmes, R. R. *Pentacoordinated Phosphorus Structure and Spectroscopy*, ACS Monograph 175, American Chemical Society: Washington, DC, 1980, Vols. I and II; Holmes, R. R. *Acc. Chem. Res.* **1998**, *31*, 535; Arduengo, A. J., III; Stewart, C. A. *Chem. Rev.* **1994**, *94*, 1215.
6. **Typical procedure for the synthesis of compounds 5a–f**: A solution of bis-Grignard reagent **2** (n=2, 1 mmol) in THF was added dropwise, under a dry nitrogen atmosphere, to a solution of **1** (1.0 mmol) in THF (15–25 mL) at room temperature. The mixture was stirred for 30 min and allowed to stand for an additional 150 min, always at room temperature. A solution of mono-Grignard reagent (1.1 mmol) (or alcoholate, 2.0 mmol) was then added. The reaction mixture was allowed to stand for 25 h at room temperature then treated with elemental sulfur (2.0 mmol) for 60 min, quenched with H_2O and extracted with CH_2Cl_2. The organic layer was dried over anhydrous sodium sulfate and concentrated 'in vacuo'. Compounds **5a**–**f** (50–80%) and **7** (whose spectral data are in agreement with Ref. 7) were purified by FC on a silica gel column. According to spectral data the purity of products **5a**–**f** and **7** is higher than 98%.

2,9-Dimethyl-11-(1-methylbutyl)-11*H*-11λ^5-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5a): Greasy solid, 75% yield, R_f = 0.53 (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$) 8.75–8.63 (m, 2H), 7.38–7.05 (m, 4H), 2.40–0.80 (m, 5H, CH_2 and CH), 2.38 (s, 3H, CH_3), 2.36 (s, 3H, CH_3), 0.88 (dd, 3H, J_{PH} = 20.9 Hz, J_{HH} = 6.9 Hz, CH_3CH), 0.66 (t, 3H, J = 7.1 Hz, CH_3CH_2); δ_C (75.56 MHz, $CDCl_3$): 140.8 (d, J = 11.1 Hz), 140.4 (d, J = 11.2 Hz), 139.0 (d, J = 12.2 Hz), 138.7 (d, J = 12.0 Hz), 138.4 (d, J = 6.1 Hz), 138.1 (d, J = 5.3 Hz), 132.6 (d, J = 3.0 Hz), 132.4 (d, J = 3.0 Hz), 131.4 (d, J = 8.9 Hz), 130.9 (d, J = 8.6 Hz), 38.4 (d, J = 53.3 Hz), 30.6 (d, J = 135.8 Hz), 21.4 (s), 21.3 (s), 20.3 (d, J = 14.6 Hz), 13.8 (d, J = 8.9 Hz), 12.7 (s); δ_P (121.47 MHz, $CDCl_3$): 65.0 (m); MS (m/z, %): 378 (M^+, 8), 308 (31), 275 (100), 243 (36), 211 (23), 185 (46), 121 (10); IR ν (cm^{-1}): 488 (S–S), 661 and 717 (P=S), 1116 (PC), 1455, 1584; HRMS calcd for $C_{19}H_{23}PS_3$: 378.0699, found: 378.0691.

2,9-Dimethyl-11-(phenyl)-11*H*-11λ^5-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5b): Greasy solid, 50% yield, R_f = 0.45 (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$): 8.58 (dm, 2H, $^3J_{P-H}$ = 16.6 Hz), 7.42–7.20 (m, 9H), 2.43 (s, 6H, CH_3); δ_C (75.56 MHz, $CDCl_3$): 139.8* (d, J = 70.1 Hz), 139.5 (d, J = 12.8 Hz), 139.1 (d, J = 13.1 Hz), 139.0 (d, J = 7.4 Hz), 133.7 (d, J = 83.0 Hz), 132.8 (d, J = 2.9 Hz), 131.3 (d, J = 8.9 Hz), 130.7 (d, J = 3.3 Hz), 130.3 (d, J = 11.3 Hz), 128.3 (d, J = 13.3 Hz), 21.3 (s) (all the signals marked with * for compounds **5** are tentatively assigned); δ_P (121.47 MHz, $CDCl_3$): 49.0 (m); MS (m/z, %): 384 (M^+, 59), 352 (14), 320 (74), 275 (70), 243 (100), 211 (51), 185 (62); IR ν, (cm^{-1}): 488 (S–S), 690 and 745 (P=S), 1100 (PC), 1583; HRMS calcd for $C_{20}H_{17}PS_3$: 384.0230, found: 384.0221.

11-(2-Chlorophenyl)-2,9-dimethyl-11*H*-11λ^5-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5c): greasy solid; 80% yield, R_f = 0.36 (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$): 8.65–8.48 (m, 1H), 7.65–7.47 (m, 2H), 7.45–7.30 (m, 5H), 7.14 (d, 2H, J = 7.8 Hz), 2.23 (s, 6H, CH_3); δ_C (75.56 MHz, $CDCl_3$): 139.2 (d, J = 13.3 Hz), 136.2* (d, J = 82.2 Hz), 138.7 (d, J = 6.1 Hz), 136.5 (d, J = 10.9 Hz), 136.3 (d, J = 3.2 Hz), 135.3 (d, J = 13.2 Hz), 133.1 (d, J = 87.9 Hz), 133.2 (d, J = 2.0 Hz), 132.0 (d, J = 3.4 Hz), 131.5 (d, J = 9.5 Hz), 130.9 (d, J = 6.1 Hz), 127.0 (d, J = 12.0 Hz), 21.3 (s); δ_P (121.47 MHz, $CDCl_3$): 47.0 (m); MS (m/z, %): 418 (M^+, 2), 383 (100), 275 (6), 243 (10), 211 (8), 185 (10), 121 (5); IR, ν (cm^{-1}): 484 (S–S), 506, 633 and 739 (P=S), 1111 (PC), 1261, 1422, 1456, 1578; HRMS calcd for $C_{20}H_{16}ClPS_3$: 417.9840, found: 417.9832.

2,9-Dimethyl-11-(1-methyl-2-propenyl)-11*H*-11λ^5-dibenzo-[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5d): Greasy solid, 80% yield, R_f = 0.58 (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$): 8.75 (dd, 1H, J_{P-H} = 15.9 Hz, J_{H-H} = 1.4 Hz), 8.60 (dd, 1H, J = 15.7 Hz, J = 1.6 Hz), 7.45–7.30 (m, 2H), 7.25–7.12 (m, 2H), 5.75–5.50 (m, 1H, HC=CH_2), 5.00–4.90 (m, 1H, *cis*-HC=CH_2), 4.85–4.70 (m, 1H, *trans*-HC=CH_2), 4.40–4.20 (m, 1H, $CHCH_3$), 2.45 (s, 3H, CH_3), 2.41 (s, 3H, CH_3), 1.07 (dd, J_{P-H} = 20.1 Hz, J_{H-H} = 6.9 Hz, CH_3CH); δ_C (75.56 MHz, $CDCl_3$): 141.0 (d, J = 10.9 Hz), 140.8 (d, J = 11.6 Hz), 140.4* (d, J = 83.2 Hz), 140.2* (d, J = 83.0 Hz), 138.9 (d, J = 12.2 Hz), 138.7 (d, J = 12.5 Hz), 138.4 (d, J = 5.9 Hz), 138.1 (d, J = 5.8 Hz), 134.7 (d, J = 6.6 Hz), 132.5 (d, J = 3.0 Hz), 132.4 (d, J = 3.1 Hz), 131.2 (d, J = 8.9 Hz), 131.0 (d, J = 9.2 Hz), 118.0 (d, J = 13.1 Hz), 44.3 (d, J = 51.3 Hz), 21.3 (s), 13.6 (d, J = 2 Hz); δ_P (121.47 MHz, $CDCl_3$): 62.1 (m); MS (m/z, %): 362 (M^+, 22), 307 (100), 275 (12), 243 (78), 185 (37); IR ν (cm^{-1}): 495 (S–S), 645 and 737 (P=S), 820, 1117, 1449, 1582, 1631; HRMS calcd for $C_{18}H_{19}PS_3$: 362.0386, found: 362.0380.

11-Ethoxy-2,9-dimethyl-11*H*-11λ^5-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5e): Greasy solid; 60% yield, R_f = 0.57 (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$): 8.55 (dd, 2H, $^3J_{P-H}$ = 18.7 Hz, $^4J_{H-H}$ = 1.4 Hz), 7.39 (dd, 2H, J = 7.7 Hz, J = 5.2 Hz), 7.25–7.19 (m, 2H), 4.05–3.85 (m, 2H, OCH_2), 2.44 (s, 6H, CH_3), 1.27 (t, 3H, J = 7.1 Hz); δ_C (75.56 MHz, $CDCl_3$): 16.2 (d, J = 8.1 Hz), 21.3 (s), 61.4 (d, J = 6.8 Hz), 131.2 (d, J = 10.8 Hz), 132.9 (d, J = 2.9 Hz), 135.1 (d, J = 108.4 Hz), 138.3 (d, J = 12.6 Hz), 138.4 (d, J = 6.8 Hz), 138.8 (d, J = 13.4 Hz); δ_P (121.47 MHz, $CDCl_3$): 86.9 (m); MS (m/z, %): 352

(M^+, 54), 320 (22), 275 (57), 259 (100), 243 (61), 211 (38), 185 (30), 121 (14); IR ν (cm^{-1}): 484 (S–S), 506, 635 and 717 (P=S), 1028 (POC), 1111 (PC), 1256, 1378, 1456; HRMS calcd for $C_{16}H_{17}OPS_3$: 352.0179, found: 352.0170. **2,9-Dimethyl-11-(2-methylbutoxy)-11*H*-11λ^5-dibenzo[*c*,*f*][1,2,5]dithiaphosphepine-11-thione (5f)**: Greasy solid; 70% yield, $R_f = 0.63$ (petroleum light:dichloromethane, 2:1); δ_H (300 MHz, $CDCl_3$): 8.57 (dd, 2H, $^3J_{P-H} = 16.8$ Hz, $^4J_{H-H} = 1.4$ Hz), 7.39 (dd, 2H, $^3J_{H-H} = 7.6$ Hz, $^4J_{P-H} = 5.2$ Hz), 7.22 (d, 2H, $^3J_{H-H} = 7.6$ Hz), 3.75–3.58 (m, 2H, OCH_2), 2.44 (s, 6H, CH_3), 1.70–1.00 (m, 3H, CH_2 and CH), 0.87 (d, 3H, $^3J_{H-H} = 6.7$ Hz, CH_3CH), 0.81 (t, 3H, $J = 7.4$ Hz, CH_3CH_2); δ_C (75.56 MHz, $CDCl_3$): 138.7 (d, $J = 14.7$ Hz), 138.6* (d, $J = 6.0$ Hz), 138.5 (d, $J = 11.8$ Hz), 135.0 (d, $J = 108.8$ Hz), 132.8 (d, $J = 2.9$ Hz), 131.2 (d, $J = 10.7$ Hz), 69.7 (d, $J = 7.6$ Hz), 35.3 (d, $J = 8.4$ Hz), 25.7 (s), 21.3 (s), 16.3 (s), 11.1 (s); δ_P (121.47 MHz, $CDCl_3$): 87.3 (m); MS (*m*/*z*, %): 374 (M^+, 5), 324 (20), 275 (8), 259 (100), 211 (14), 185 (10), 121 (5); IR ν (cm^{-1}): 500 (S–S), 650 and 717 (P=S), 994 (POC), 1117 (PC), 1256, 1378, 1456; HRMS calcd for $C_{19}H_{23}OPS_3$: 394.0649, found: 394.0641.

7. For a review about phosphenium ions, see: Cowley, A. H.; Kempt, R. A. *Chem. Rev.* **1985**, *85*, 367.
8. For a review about phosphoranide, see: Dillon, K. B. *Chem. Rev.* **1994**, *94*, 1441.
9. For a review about ligand-coupling reactions of hypervalent species, see: Oae, S.; Uchida, Y. *Acc. Chem. Res.* **1991**, *24*, 202.
10. (a) Schmutzler, R. *Inorg. Chem.* **1964**, *3*, 421; (b) Lee, J. D.; Goodacre, G. W. *Acta Crystallogr., Sect. B* **1970**, *26*, 507.
11. Douglass, M. R.; Marks, T. J. *J. Am. Chem. Soc.* **2000**, *122*, 1824.
12. Baccolini, G.; Boga, C.; Buscaroli, R. A. *Synthesis* **2001**, 1938.
13. Block, E.; Ofori-Okai, G.; Zubieta, J. *J. Am. Chem. Soc.* **1989**, *111*, 2327.