

The Reaction of Alkyl-substituted Thioanisoles with PCl_3 and AlCl_3 : a Route to [1,2,3]Benzothiadiphospholo[2,3-*b*][1,2,3]benzothiadiphosphole Derivatives

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The synthesis of [1,2,3]benzothiadiphospholo[2,3-*b*][1,2,3]benzothiadiphosphole derivatives starting from alkyl-substituted thioanisoles and PCl_3 - AlCl_3 is reported. The reaction is carried out at reflux in the absence of solvent and the yields are dependent on the starting sulphide. These new heterocycles can be purified by simple filtration on a Florisil column and have been characterized by ^1H -, ^{13}C -, $(^1\text{H})^{31}\text{P}$ -n.m.r. and mass spectroscopy analyses. New unexpected findings are also described.

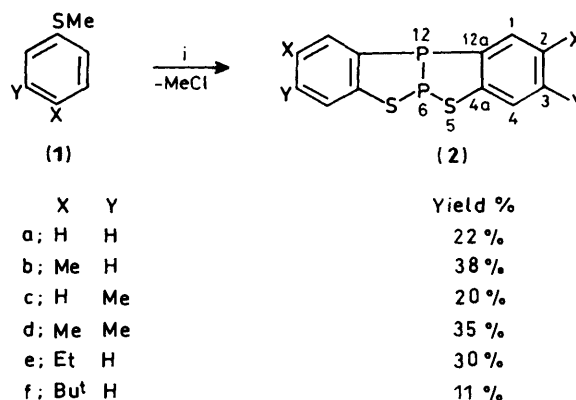
The use of AlCl_3 to activate phosphorus trichloride towards electrophilic reactions with aromatic compounds¹ has proved to be a standard method for the preparation of aryldichlorophosphines. Moreover, this Friedel-Crafts type reaction has been extended to the synthesis of a wide variety of phosphorus heterocyclic compounds related to phosphanthracenes,² differing in the second heteroatom and substituents in the aromatic ring. In particular it has been long known that the reaction of bis (*p*-tolyl) sulphide with phosphorus trichloride in the presence of AlCl_3 at reflux temperature leads to 2,8-dimethylphenothiaphosphinic acid.³ This synthesis represents one of the few examples reported in literature in which the Friedel-Crafts reaction with PCl_3 has been applied to aryl sulphides.

During our recent studies⁴ on the use of phosphorus trichloride in organic synthesis, we speculated whether heterocyclic compounds containing both phosphorus and sulphur might be synthesized from the reaction of *alkyl* aryl sulphides with PCl_3 and AlCl_3 . We thought that the aryldichlorophosphine obtained might react with either the sulphur (and eliminate the alkyl chloride) or with its vicinal alkyl carbon atom, to give 1,2-benzothiadiphosphete or 1,3-benzothiadiphosphole derivatives respectively. Surprisingly, however, this reaction with thioanisole gave [1,2,3]benzothiadiphospholo[2,3-*b*][1,2,3]benzothiadiphosphole (**2a**) in a one-pot procedure. In this facile synthesis the breaking of the S-Me bond and the concomitant formation of two new C-P, two P-S, and one P-P bonds are involved. In a previous communication,⁵ we described the first example of this new heterocycle and its X-ray structure. We now report the details of the reaction and the study of a possible generalization of this method using several substituted thioanisoles.

Results and Discussion

The thioanisoles (**1**) and PCl_3 - AlCl_3 were allowed to reflux in the absence of solvent for *ca.* 2 h. The course of the reaction was monitored by t.l.c. and g.l.c.-m.s. analysis and compounds (**2**) were purified by simple filtration on a Florisil column. Scheme 1 depicts the products (**2**) obtained on reaction of different alkyl-substituted thioanisoles (**1**) with PCl_3 - AlCl_3 .

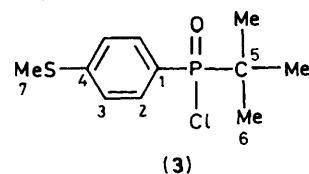
The best results were obtained using a ratio (1)- PCl_3 - AlCl_3 of 1:3:0.75. The yields of products (**2**) were also dependent on the starting sulphide. Methyl *p*-tolyl sulphide (**1b**) provided the higher yield. In the case of methyl *m*-tolyl sulphide (**1c**), the reaction proved to be regioselective, giving (**2c**), one of the two possible isomers; similar behaviour was observed for 3,4-(dimethyl)thioanisole (**1d**), which afforded only compound (**2d**). Methyl *o*-tolyl sulphide and 2,4- and 2,5-(dimethyl)thioanisole gave an appreciable amount of the corresponding fused benzo-1,2,3-thiadiphospholes. Compounds (**2**) are stable to air and



Scheme 1. Reagents and conditions: i, PCl_3 - AlCl_3 , reflux

moisture and this feature allows their easy purification from other unidentified products, which are probably very unstable. Attempts to perform this synthesis in the presence of solvents (*e.g.*, nitrobenzene, dichloromethane, chloroform, hexane, acetonitrile) failed.

The reaction appears to be favoured when the methyl group occupies the *para*-position, presumably reducing the by-products arising from the electrophilic substitution of PCl_3 in that position. In addition the *ortho*-substituent does not allow the formation of (**2**) probably because of the steric hindrance of the methyl group. The reaction has also been studied using *p*-ethyl- (**1e**) and *p*-*t*-butyl- (**1f**) thioanisoles giving the corresponding products (**2e**) and (**2f**). In the latter case (**2f**) was obtained in small amounts, compound (**3**) being the major unexpected product. Compound (**3**) was characterized by spectroscopic and analytical data.



The structural proof of the fused systems (**2**) rests on spectroscopic data. In particular the mass spectrum (Table) exhibits for all compounds a molecular ion peak with the isotopic distribution of two sulphur atoms and a base peak at $M - 63$ which corresponds to the loss of a P-S fragment.

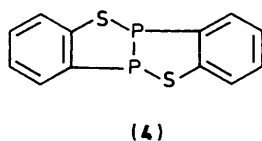
The $[^1\text{H}]^{31}\text{P}$ n.m.r. spectrum (Table) shows a characteristic AB spin system corresponding to a P-P bond in which the phosphorus atoms are not magnetically equivalent. For this

Table. Physical, analytical, and selected spectral data in CDCl₃ solutions of (2a–e)

Compound (formula)	M.p. (°C)	Found (requires) C, H, P, S	<i>m/z</i> Found (requires)	Base peak (<i>M</i> ⁺ – 63)	δ_{H}^a (<i>J</i> _{HH}) ^c		δ_{P}^c (<i>J</i> _{PP}) ^c		δ_{C}^a (<i>J</i> _{CP}) ^c		
					1-H	4-H	P-6	P-12	C-1	C-4a	C-12a
(2a) (C ₁₂ H ₈ P ₂ S ₂)	92–94 Pale yellow	51.8 (51.81) 2.9 (2.90) 22.3 (22.29) 23.05 (23.00)	277.9546 (277.9543)	215	7.63(t) (8.0)	7.36(d) (7.5)	65.7 85.1 (212.2)		131.1 (27.5)	145.1	139.1 (29.5)
(2b) (C ₁₄ H ₁₂ P ₂ S ₂)	157–159 White	54.9 (54.90) 3.9 (3.95) 20.25 (20.25) 20.9 (20.90)	305.9857 (305.9855)	243	7.41(d) (8.0)	7.25(d) (7.5)	65.4 88.3 (211.5)		131.7 (27.7)	141.6	139.6 (29.6)
(2c) (C ₁₄ H ₁₂ P ₂ S ₂)	147–150 White	54.9 (54.90) 3.95 (3.95) 20.25 (20.25) 20.9 (20.90)	305.9856 (305.9855)	243	7.50(t) (7.7)	7.18(s)	64.1 87.3 (211.5)		130.8 (27.7)	145.2	136.6 (29.6)
(2d) (C ₁₆ H ₁₆ P ₂ S ₂)	164–167 White	57.5 (57.48) 4.8 (4.83) 18.55 (18.55) 19.15 (19.14)	334.0170 (334.0168)	271	7.37(d) (8.0)	7.14(s)	62.8 85.9 (212.0)		132.0 (28.0)	142.0	136.6 (30.0)
(2e) (C ₁₆ H ₁₆ P ₂ S ₂)	109–111 White	57.45 (57.48) 4.8 (4.83) 18.55 (18.55) 19.2 (19.14)	334.0171 (334.0168)	271	7.46(d) (8.4)	7.27(d) (8.0)	63.0 83.8 (212.8)		130.9 (27.7)	142.1	140.1 (29.8)

^a δ From Me₄Si. ^b δ From H₃PO₄ (85%); downfield shifts are positive. ^c Values in parentheses are coupling constants in Hz.

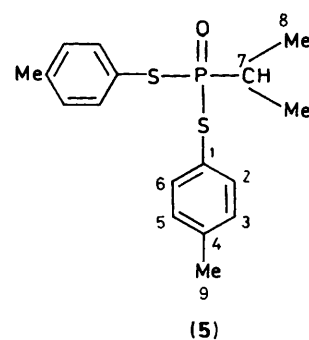
reason we can exclude the possibility of formation of [1,2,3]-benzothiadiphospholo[3,2-*b*][1,2,3]benzothiadiphosphole (4)



with two equivalent phosphorus atoms. Thus this reaction is highly selective giving only fused 1,2,3-benzothiadiphospholes of type (2a–f). The assignments of P-6 and P-12 are in accordance with related compounds.⁶ In the ¹³C n.m.r. spectra (Table), the ³¹P–¹³C coupling constants for C-1 and C-12a are large and represent a feature of all compounds (2).^{*} These characteristic spectroscopic data can be used for easy identification of other compounds related to (2). The ¹H n.m.r. spectral data (Table) have been essential for clarifying the structures of (2c) and (2d); other possible positional isomers can be excluded on the basis of the multiplicity of the aromatic signals.

In order to verify whether compound (2) is formed with other substituted sulphides, we carried out the reaction using the ethyl and the isopropyl *p*-tolyl sulphides; in the former case compound (2b) was obtained in fairly good yields, in the latter (2b) was not recovered, but g.l.c.-m.s. analysis of the reaction mixture showed three main peaks corresponding to the following compounds: 4-MeC₆H₄SH, (4-MeC₆H₄S)₃P, and (4-MeC₆H₄S)₂(1-Prⁱ)PO (5).

The first two products were identified by comparison with authentic samples and the third was characterized by exact mass, ¹H-, [¹H]³¹P-, and ¹³C-n.m.r. and i.r. spectra, and presents the isopropyl group bonded to the phosphorus atom. When 4-(methyl)thiophenol was used, compound (2b) was



recovered only in traces, the major product being the expected (4-MeC₆H₄S)₃P. The corresponding thiophenols and tris-(arylthio)phosphites were always observed as by-products of all the reactions with thioanisoles, in amounts depending on the starting sulphide. Breakage of the S–R bond also occurred when R ≠ Me but in these cases the yield of (2b) or the formation of other compounds arising from the S–R cleavage decreased.

A series of different substituents (X = Br, Cl, NHCOMe, OMe) in the aromatic ring of the starting sulphide was investigated, but none of them led to the formation of (2). If it is possible to generalize from such a small number of substituents, it would appear that (2) is not formed when a withdrawing substituent such as Br or Cl is present or when a group, such as NHCOMe or OMe may interact with PCl₃ or AlCl₃.

Several other metal halides (BF₃·EtO₂, FeCl₃, MgCl₂, SnCl₄, TiCl₃, TiCl₄, ZnCl₂) were examined since one can imagine a number of potential Lewis acids similar to AlCl₃, but curiously (1) did not react and was recovered unchanged.

In conclusion, we have found a facile synthesis of a new class of phosphorus and sulphur-containing heterocycles in a simple one-pot reaction and we have generalized this method using several alkyl-substituted thioanisoles. In addition we have found that AlCl₃ is fundamental in the formation of both the fused systems (2) and the other products in which the S–R bond cleavage is involved. For this reason we think that AlCl₃ also

* The assignments of the other carbon signals are based on the multiplicity of direct and long-range ¹H–¹³C and ³¹P–¹³C coupling constants.

plays a determinant role in the formation of S-P and P-P bonds and the exploitation of this new reactivity of $\text{PCl}_3\text{-AlCl}_3$ may be interesting for the synthesis of other heterocyclic systems.

Experimental

^1H -, ^{13}C -, and $[\text{H}^1]^{31}\text{P}$ -N.m.r. spectra were recorded at 300.00, 75.43, and 121.44 MHz respectively with a Bruker CXP 300 instrument.* ^1H - and ^{13}C -N.m.r. chemical shifts are given in p.p.m. from Me_4Si and ^{31}P n.m.r. chemical shifts from H_3PO_4 (85%) (external standard) in CDCl_3 solutions; to facilitate the notation of ^{13}C n.m.r. data for (3) and (5) an unofficial numbering system is adopted. Mass spectra were recorded with a VG 7070 spectrometer or with an HP 59970 workstation formed by an HP-5890 gas chromatograph equipped with a methyl silicone capillary column and by an HP-5970 mass detector. I.r. spectra were recorded on a Perkin-Elmer 983 spectrophotometer. M.p.s are uncorrected and were determined with a Buchi apparatus. Light petroleum refers to the fraction boiling 40–60 °C. Commercial sulphides (1a,b) and aluminium chloride were used without purification. PCl_3 was distilled before use. Methyl *m*-tolyl sulphide (1c), methyl *o*-tolyl sulphide, 2,4-, 3,4- (1d), and 2,5-(dimethyl)thioanisoles, and ethyl and isopropyl *p*-tolyl sulphides were synthesized from the corresponding thiophenols and alkyl halides (molar ratio 1:1) in the presence of triethylamine in acetone solution; *p*-ethyl- (1e) and *p*-*t*-butyl- (1f) thioanisoles were synthesized from the corresponding halogen derivatives and sodium methanethiolate.⁸ Yields of (2) are reported for isolated products from starting sulphides.

Reaction of Thioanisoles (1a–e) with $\text{PCl}_3\text{-AlCl}_3$: General Procedure.—Thioanisoles (1) (20 mmol) were added dropwise to a suspension of AlCl_3 (15 mmol) in PCl_3 (60 mmol) in the absence of solvent under a nitrogen atmosphere. The mixture was allowed to reflux for ca. 2 h and the course of the reaction was monitored by t.l.c. [light petroleum as eluant (R_F 0.10–0.15)] and g.l.c.-m.s. analysis. After evaporation under reduced pressure of the excess of PCl_3 the crude product was isolated by filtration on a Florisil column eluting with cyclohexane-dichloromethane (80:20). Compounds (2) were obtained in a pure form by recrystallization from light petroleum and dichloromethane. The corresponding thiophenols and tris-(phenylthio)phosphites were detected as by-products (5–10%) of the reaction and characterized by comparison with authentic samples. Yields, m.p.s and selected spectroscopic data are reported in Scheme 1 and in the Table.

Reaction of Ethyl *p*-Tolyl Sulphide with $\text{PCl}_3\text{-AlCl}_3$. Ethyl *p*-tolyl sulphide was treated with $\text{PCl}_3\text{-AlCl}_3$ as described above. Compound (2b) was obtained in 25% yield.

Reaction of Isopropyl *p*-Tolyl Sulphide with $\text{PCl}_3\text{-AlCl}_3$.—The reaction was carried out as previously described. G.l.c.-m.s. analysis of the reaction mixture did not reveal formation of (2a) in detectable amounts. After evaporation of PCl_3 under reduced pressure the mixture was treated with water, extracted with diethyl ether, and dried (Na_2SO_4). Silica gel flash chromatography [light petroleum diethyl ether (1:1) as eluant] afforded

mainly 4-(methyl)thiophenol, tris(*p*-tolylthio)phosphite, and compound (5) in 5, 10, and 16% yield respectively. The first two products were identified by comparison with authentic samples. Compound (5) was recovered as a thick oil, R_F 0.20 (CH_2Cl_2); $\delta_{\text{H}}(\text{CDCl}_3)$ 1.33 (dd, 6 H, Me, J_{HH} 7.0 Hz and J_{HP} 21.0 Hz), 2.00–2.66 (m, 1 H, CH), 2.33 (s, 6 H, Me), 7.20 (d, 4 H, ArH, J_{HH} 8.0 Hz), and 7.46 (d, 4 H, ArH); $\delta_{\text{C}}(\text{CDCl}_3)$ 17.9 (C-8), 22.4 (C-9), 36.8 (d, C-7, J_{HP} 66.3 Hz), 121.6 (C-4), 128.9 (C-3, C-5), 134.3 (C-2, C-6), and 138.0 (C-1); $[\text{H}^1]^{31}\text{P}$ n.m.r. (CDCl_3) 68.7; ν_{max} (liquid film) 1 203 cm^{-1} (P=O) (Found: M^+ , 336.0776. Calc. for $\text{C}_{17}\text{H}_{21}\text{OPS}_2$: 336.0771).

Reaction of *p*-(*t*-Butyl)thioanisole (1f) with $\text{PCl}_3\text{-AlCl}_3$.—*p*-(*t*-Butyl)thioanisole was treated with $\text{PCl}_3\text{-AlCl}_3$ in the usual manner. After evaporation of PCl_3 under reduced pressure, compounds (2f) and (3) were separated on a Florisil column eluting with light petroleum-dichloromethane from 95.5 to 30.70. It was not possible to obtain (2f) in pure form; it was recovered as an oil in approximately 11% yield: $\delta_{\text{H}}(\text{CDCl}_3)$ 1.33 (s, 9 H, Me), 7.18–7.32 (m, 2 H, ArH), and 7.68 (d, 1 H, ArH, J_{HP} 9.0 Hz); $[\text{H}^1]^{31}\text{P}$ n.m.r. (CDCl_3) 64.8 (d, P-6) and 77.4 (d, P-12, J_{PP} 216.5 Hz) (Found: M^+ , 390.0796. Calc. for $\text{C}_{30}\text{H}_{24}\text{S}_2\text{P}_2$: 390.0793), m/z 327 (base peak, $M^+ - 63$). Compound (3) was obtained in 32% yield, R_F 0.30 (CH_2Cl_2); m.p. 117–120 °C; $\delta_{\text{N}}(\text{CDCl}_3)$ (d, 9 H, Me, J_{HP} 19.0 Hz), 2.53 (s, 3 H, Me), 7.33 (dd, ArH, J_{HH} 7.5 Hz, J_{HP} 3.6 Hz), and 7.76 (dd, 2 H, ArH, J_{HH} 7.5 Hz, J_{HP} 11.0 Hz), $\delta_{\text{C}}(\text{CDCl}_3)$ 16.0 (C-7), 25.3 (C-6), 39.9 (d, C-5, J 77.4 Hz), 123.8 (d, C-2, J 13.3 Hz), 124.2 (d, C-1, J 104.0 Hz), 131.5 (d, C-3, J 11.1 Hz), and 144.5 (C-4); $[\text{H}^1]^{31}\text{P}$ -n.m.r. (CDCl_3) 68.6; ν_{max} (KBr) 1 228 cm^{-1} (P=O) (Found: M^+ 262.0354. Calc. for $\text{C}_{11}\text{H}_{16}\text{ClOPS}$: 262.0348).

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* ^{13}C , ^{31}P , and ^1H N.m.r. data of compounds (2) are available from the British Library Lending Division, Supplementary Publication 56725 (3 pages), for details see 'Instructions for Authors,' *J. Chem. Soc., Perkin Trans. 1*, 1988, Issue 1.