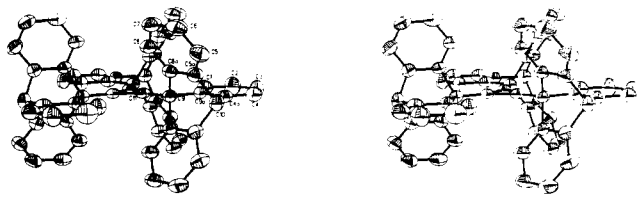

Figure 1. Stereoview of the X-ray structure of the cation in tris(9-triptycyl)cyclopropenium perchlorate (**2**) with thermal motion ellipsoids (50% probability) and atom labels. Hydrogen atoms are suppressed for clarity.

of the three blades is replaced by a three-toothed gear and in which structural rigidity is induced by the odd number of interlocked rotors.[9]

The axes of the Tp gears in Tp_3MX are coextensive with the C(9)-M bonds to form a pyramidal array with M at the apex. In **2** the three bevel gear axes are coplanar, and their extensions intersect at the center of the molecule. This compound was readily prepared from bis(9-anthryl)cyclopropenone:[10] addition of benzyne gave bis(9-triptycyl)cyclopropenone,[4] and addition of TpLi to the latter followed by reaction with $HClO_4$ afforded **2**.[4] The number of signals and their relative intensities in the ^{13}C and ^1H NMR spectra[11] are consistent only with a statically geared triskelion (C_{3h}) conformation which is also adopted by the molecule in the solid state (Figure 1).[12] There is no evidence of signal broadening up to 80 °C (acetonitrile), and the lower limit for site exchange is therefore ca. 17 kcal mol^{-1}.

In sum, torsional motion of the three Tp rotors in **1** and **2** is frozen because *uncorrelated as well as correlated rotation is mechanically disallowed in a closed cyclic array consisting of an odd number of securely meshed gears.* Further studies of these and related compounds are in progress.

Acknowledgment. We thank the National Science Foundation (CHE-8510067) for support of this work.

Supplementary Material Available: Tables of atomic coordinates, bond lengths and bond angles with standard deviations, and anisotopic thermal parameters for **2** (5 pages); table of observed and calculated structure factors for **2** (7 pages). Ordering information is given on any current masthead page.

(9) Molecules of the type $(Me_3C)_3MX$ also have C_3 ground-state symmetry, but the three *tert*-butyl groups are not securely gear-meshed, and enantiomerization takes place at very low temperatures on the NMR time scale by processes that involve conrotatory motion of two or all three of the *tert*-butyl groups. See: Hounshell, W. D.; Iroff, L. D.; Wroczynski, R. J.; Mislow, K. *J. Am. Chem. Soc.* **1978**, *100*, 5212. Wroczynski, R. J.; Mislow, K. *J. Am. Chem. Soc.* **1979**, *101*, 3980.

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(11) $^{13}C\{^1H\}$ NMR (125.8 MHz, CD_3CN, ambient temperature) δ 188.75 (cyclopropenium carbon C(11)), 146.28, 137.44 (aromatic carbons C(4a) and C(9a)), 145.37, 140.62 (aromatic carbons C(5a) and C(8a)), 128.18, 126.06, 124.50, 123.76 (aromatic carbons C(1)-C(4)), 129.47, 127.06, 126.90, 122.97 (aromatic carbons C(5)-C(8)), 62.01 (C(9)), 53.56 (C(10)). ^1H NMR (500 MHz, CD_3CN, ambient temperature) δ 7.84 (dd, 2 H, H(5)), 7.54 (dd, 1 H, H(4)), 7.29 (ddd, 2 H, H(6)), 7.23 (dd, 2 H, H(8)), 6.93 (ddd, 2 H, H(7)), 6.89 (ddd, 1 H, H(3)), 6.82 (dd, 1 H, H(1)), 6.01 (s, 1 H, H(10)), 5.90 (ddd, 1 H, H(2)). Resonance assignments by NOE difference and COSY experiments.

(12) Crystals of **2** are hexagonal, space group $P6_3/m$ (No. 176), with $a = b = 15.145$ (5) Å, $c = 13.617$ (4) Å, $V = 2704$ (1) Å^3, and $d_{calcd} = 1.32$ g cm^{-1} for $Z = 2$ ($C_{63}H_{39}ClO_4$, $M = 895.5$). Intensity data were measured on a Nicolet R3m diffractometer with $3° < 2\theta < 114°$ with graphite monochromated Cu Kα radiation at room temperature. Of 1281 unique reflections, 1148 were considered to be observed [$|F_o| > 3\sigma(F_o)$] after applying Lorentz and polarization corrections. Three additional reflections (010, 002, and 004) were omitted because $F_o \ll F_{calcd}$ for these reflections, presumably due to extinction. The structure was solved in $P6_3$ with the SHELXTL direct methods software and was refined in $P6_3/m$. All non-hydrogen atoms were refined anisotropically, hydrogen atoms were included at standard positions (C-H, 0.96 Å; C-C-H 120° or 109.5°) and refined isotropically with a riding model. Refinement with 130 least-squares parameters converged at $R = 0.056$ and $R_w = 0.059$. The unit cell contains two molecules with crystallographic C_{3h} ($\bar{6}$) site symmetry. The perchlorate anion is disordered, and no satisfactory scheme was found to model this disorder by a superposition of tetrahedral perchlorate anions with standard bond lengths and angles.

2-Phosphino- and 2-Phosphinylbenzenethiols: New Ligand Types

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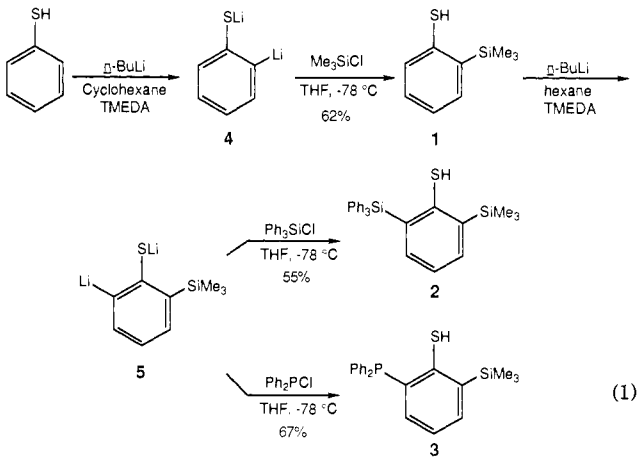
Compounds containing both thiol and phosphino or phosphinyl groups should be particularly useful as bidentate or polydentate ligands. A few examples of such compounds and their metal complexes are known,[1] but general syntheses are not available. It has been recently reported[2] that 2- and 2,6-substituted thiophenols such as **1** and **2**[3] (eq 1) and related 3- and 3,6-substituted



(1)

pyridinethiols[4] can be readily prepared from the parent compounds by ortho lithiation-electrophilic substitution procedures, and that these substituted thiols form a variety of novel transition-metal complexes.[4,5] We find that such methods can also be used to make 2-phosphino- and 2-phosphinylbenzenethiols (e.g., **3**), previously unknown types of mixed phosphorus-sulfur compounds.[1b] We report the application of this useful procedure to the preparation of interesting new classes of polydentate ligands containing phosphorus, sulfur, and in some cases silicon as well as a novel heterocyclic system.

(1) (a) 2-Phosphinoethanethiol derivatives represent a related, known ligand type: Blower, P. J.; Dilworth, J. R.; Leigh, G. J.; Neaves, B. D.; Normanton, F. B.; Hutchinson, J.; Zubieta, J. *J. Chem. Soc., Dalton Trans.* **1985**, 2647. Jurkschat, K.; Uhlig, W.; Mügge, C.; Tzschach, A.; Schmidt, B.; Dräger, M. *Z. Anorg. Allg. Chem.* **1988**, *556*, 161. White, G. S.; Stephan, D. W. *Organometallics* **1988**, *7*, 903. (b) A brief report of a multistep synthesis of 2-phosphinobenzenethiol (o-$HSC_6H_4PH_2$) has appeared: Issleib, K.; Vollmer, R. *Z. Chem.* **1978**, *18*, 451. We thank Professor T. B. Rauchfuss for calling this reference to our attention.

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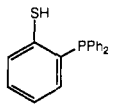
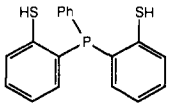
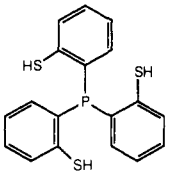
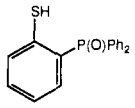
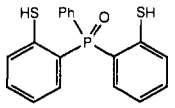
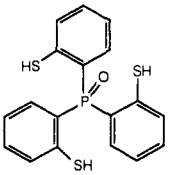
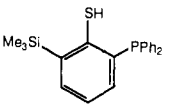
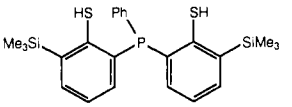
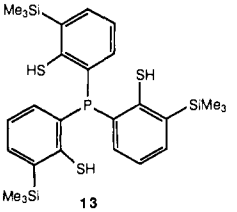
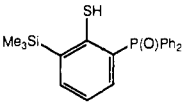
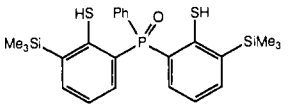
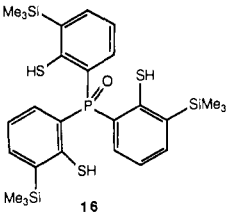
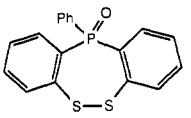
(3) 2-(Trimethylsilyl)benzenethiol[2a,c] (**1**) was treated with *n*-BuLi (2 equiv) and TMEDA (*N,N,N',N'*-tetramethylethylenediamine; 1 equiv) in hexane for 24 h, and the solid was filtered off under argon and dissolved in THF cooled to -78 °C. Chlorotriphenylsilane (0.38 equiv) in THF was added, and the mixture was worked up as previously described.[2a] Chromatography gave **2** as a colorless solid (55%; based on Ph_3SiCl): mp 141-143 °C; ^1H NMR δ 7.8-7.0 (m, 18 H), 3.58 (s, 1 H, SH), 0.46 (s, 9 H); ^{13}C NMR δ 145.1, 142.7, 140.1, 137.1, 136.3, 134.4, 134.2, 129.5, 128.0, 125.1, 0.2. Anal. (C, H).

(4) Block, E.; Gernon, M.; Kang, H.; Zubieta, J. *Angew. Chem., Int. Edn. Engl.* **1988**, *27*, 1342.

(5) (a) Block, E.; Aslam, M. *Tetrahedron* **1988**, *44*, 281. (b) Block, E.; Gernon, M.; Kang, H.; Liu, S.; Zubieta, J. *J. Chem. Soc., Chem. Commun.* **1988**, 1031. (c) Block, E.; Kang, H.; Ofori-Okai, G.; Zubieta, J. *Inorg. Chim. Acta* **1989**, *156*, 27. (d) Block, E.; Gernon, M.; Kang, H.; Ofori-Okai, G.; Zubieta, J. *Inorg. Chem.* **1989**, in press. (e) Giolando, D. M.; Rauchfuss, T. B.; Rheingold, A. L. *Inorg. Chem.* **1987**, *26*, 1636. (f) For a related approach to *o*-diphenylphosphinophenol and its coordination compounds, see: Rauchfuss, T. B. *Inorg. Chem.* **1977**, *16*, 2966.

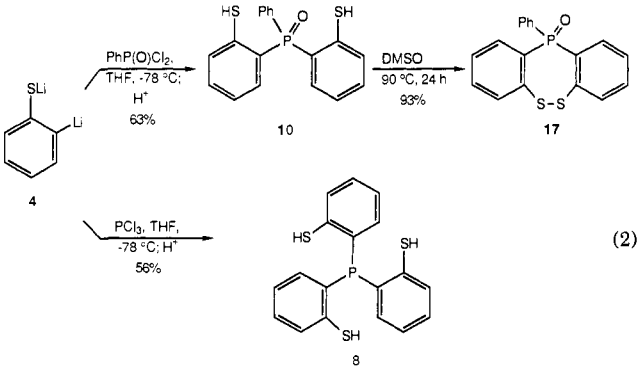
0002-7863/89/1511-2327$01.50/0

Table I. Spectroscopic Data on 2-Phosphino- and 2-Phosphinylbenzenethiols Related Compounds[a]

entry no.	compound	yield,[b] (%)	mp,[c] °C	^{1}H and ^{31}P NMR spectra[d,e]
1	 **6**	65	98–99	δ_H 7.3–6.6 (m, 14 H), 4.07 (d, J = 2.2, 1 H, SH); δ_P −13.1
2	 **7**	76	102–104	δ_H 7.5–6.7 (m, 13 H), 4.07 (d, J = 1.5, 2 H, SH); δ_P −19.9
3	 **8**	56	150–152	δ_H 7.4–6.7 (m, 12 H), 4.07 (d, J = 2.2, 3 H, SH); δ_P −26.4
4	 **9**	67	113–116	δ_H 8.0–6.8 (m, 14 H), 6.18 (s, 1 H, SH); δ_P 30.7
5	 **10**	63	121–123	δ_H 8.0–6.85 (m, 13 H), 6.19 (s, 2 H, SH); δ_P 38.7
6	 **11**	67	155–158	δ_H 8.0–6.5 (m, 15 H), δ_P, 43.8
7	 **3**	67	102–103	δ_H 7.6–6.7 (m, 13 H), 4.6 (d, J = 11.2, 1 H, SH), 0.43 (s, 9 H); δ_P −13.6
8	 **12**	61	130–133	δ_H 7.7–6.7 (m, 11 H), 4.58 (d, J = 11.8, 2 H, SH), 0.42 (s, 18 H); δ_P −20.5
9	 **13**	63	168–170	δ_H 7.51 (dd, J = 7.3, 2.5, 3 H), 7.11 (t, J = 7.2, 3 H), 6.82 (ddd, J = 7.7, 3.7, 1.8, 3 H), 4.58 (d, J = 12.5, 3 H, SH), 0.42 (s, 27 H); δ_P −27.4
10	 **14**	59	194–195	δ_H 7.8–6.8 (m, 13 H), 7.08 (s, 1 H, SH), 0.38 (s, 9 H); δ_P 35.6
11	 **15**	62	178–179	δ_H 7.8–6.8 (m, 11 H), 7.01 (s, 2 H, SH), 0.40 (s, 18 H); δ_P 42.2
12	 **16**	47	188–190	δ_H 7.86 (ddd, J = 14.19, 7.93, 1.44, 3 H), 7.56 (dd, J = 5.67, 1.54, 3 H), 7.30, (br s, 3 H, SH), 7.18 (td, J = 7.56, 2.31, 3 H), 0.36 (s, 27 H); δ_P 37.3
13	 **17**	93	210–213	δ_H 8.7–6.8 (m); δ_P 26.6

[a] Compounds **9–11** and **15** show $\nu_{P=O}$ at 1180, 1170, 1260, and 1170 cm^{-1}, respectively. [b] Yields are based on phosphorus reactants. [c] Recrystallized from ether–hexane or CH_2Cl_2–hexane. [d] Chemical shifts in ppm from internal TMS (^{1}H) or from external Ph_3P relative to 85% H_3PO_4 (^{31}P; positive chemical shifts are downfield from H_3PO_4); coupling constants are in Hz. [e] See Supplementary Material for ^{13}C NMR chemical shifts of **3** and **6–17**.

Treatment of tetrahydrofuran solutions of lithium 2-lithiobenzenethiolate (**4**) or lithium 6-(trimethylsilyl)-2-lithiobenzenethiolate (**5**) at −78 °C with chlorodiphenylphosphine, dichlorophenylphosphine, phosphorus trichloride, diphenylphosphonic chloride, phenylphosphonic dichloride, and phosphorus oxychloride gives the respective 2-mercaptophenyl or 6-(trimethylsilyl)-2-mercaptophenyl derivatives **3** and **6–16** in 47–76% yield, based on the phosphorus component (see Table I and eq 1 and 2).[6] All of the products are colorless solids with sharp melting points and satisfactory elemental analyses and spectroscopic properties, as summarized in Table I.



(2)

Hydrogen bonding between the SH and P=O groups in the phosphine oxides results in a shift in the ^{1}H NMR absorption of the SH group from δ 4.1–4.6 ppm in **6–8** and **12–14** to ca. δ 6.2–7.3 ppm in **3**, **9–11**, and **14–16**. An interesting trend is seen in the ^{31}P shifts in the series **6** → **7** → **8**, **3** → **12** → **13**, **9** → **10** → **11**, and **14** → **15** → **16**. In the first two series there is an upfield shift of 6.5–6.9 ppm each time an ortho-H is replaced by SH (or

(6) Synthesis of **6**: Solvents used to isolate products were degased and saturated with argon. Reactants and products were protected from light. Lithium 2-lithiobenzenethiolate **4** was prepared as described elsewhere[2] from thiophenol (7 g, 0.064 mol), TMEDA (22 mL, 0.142 mol), and 2.5 M *n*-butyllithium in hexane (57 mL, 0.142 mol). Solid **4** was isolated by filtration under argon on a medium Schlenck frit, washed with dry hexane (2 × 50 mL), and dissolved in dry THF (100 mL) precooled to −78 °C. A stirred solution of **4** in THF at −78 °C was then treated dropwise during 1.5 h with chlorodiphenylphosphine (10 g; equivalent to 0.045 mol (70% conversion) of **4**). The mixture was warmed to room temperature overnight, the solution was acidified with dilute ice-cold sulfuric acid, the mixture was concentrated in vacuo, and the residue was taken up in ether. The ether solution was washed with water, dried ($MgSO_4$), and concentrated to afford crude **6** (ca. 90% yield). Purification by treatment with activated charcoal in ether, filtration, and crystallization from ether–hexane gave 8.7 g (65% yield based on Ph_2PCl) of **6**, a colorless solid which after chromatography (silica gel; hexane–CH_2Cl_2) had mp 98–99 °C. Anal. (C, H) (see Table I).

ortho-SH + meta-TMS), which may be explained by an increase in γ-shielding on P by S. In the third and fourth series, with the exception of **15** → **16**, hydrogen bonding in the phosphine oxides causes downfield ^{31}P shifts, which appear to be cumulative and in opposition to the γ-effect. In the case of **16**, combined steric effects due to the three trimethylsilyl groups apparently preclude the type of extensive hydrogen bonding found in **11**. None of the shift effects observed are explained by an electronic effect of the sulfur.[7]

Phosphine oxide **10** could be oxidized to 11-phenyl-11*H*-dibenzo[*cf*][1,2,5]dithiaphosphepin-11-oxide (**17**), a new heterocyclic ring system, by heating with dimethyl sulfoxide at 90 °C for 24 h. The novel coordination chemistry and other reactions of the various new compounds reported herein will be presented elsewhere.[8]

Acknowledgment. We gratefully acknowledge support from the National Science Foundation, the National Institutes of Health, the donors of the Petroleum Research Fund, administered by the American Chemical Society, the Herman Frasch Foundation, and Société Nationale Elf Aquitaine. Funding for the 300 MHz NMR facility was provided by the National Science Foundation.

Supplementary Material Available: ^{13}C NMR chemical shifts of **3** and **6**–**17** (1 page). Ordering information is given on any current masthead page.

(7) We thank one of the referees for bringing this interesting NMR effect to our attention.

(8) For example, novel molybdenum complexes of **6** and **14** have been prepared and characterized: Block, E.; Kang, H.; Ofori-Okai, G.; Zubieta, J., manuscript submitted for publication.

The Biosynthesis of Acivicin and 4-Hydroxyacivicin from N^{δ}-Hydroxyornithine

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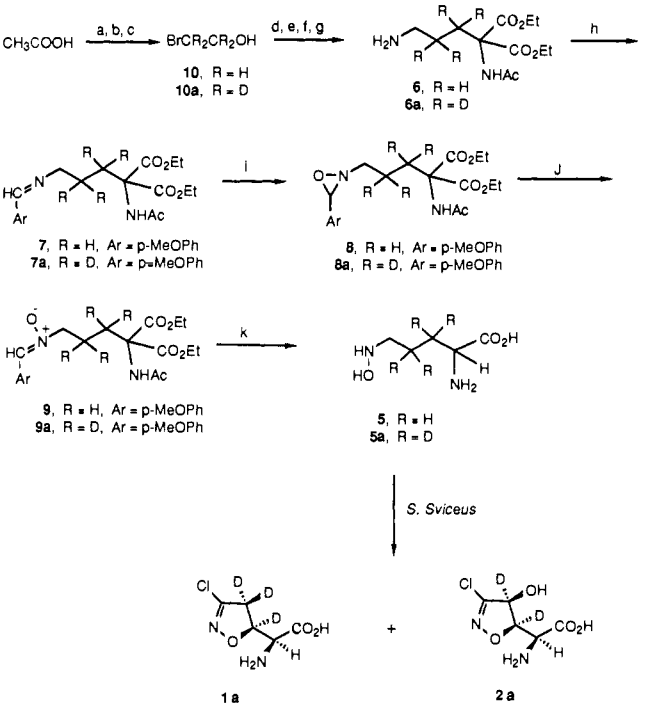
Received September 13, 1988

Acivicin (AT-125) (**1**)[1,2] and 4-hydroxyacivicin (**2**)[3] are produced from *Streptomyces sviceus*. Acivicin has potent anticancer activity[4] and has found use as an important tool for studying xenobiotic metabolism involving glutathione,[5] while **2** has approximately one-fifth the cytotoxic activity of **1**. The isoxazolidine ring upon which these structures are based occurs, at various levels of oxidation, in only a few other natural products: tricholomic acid,[6,7] ibotenic acid,[8-10] muscimol,[11] and cycloserine.[12-14] While

Scheme I



a: P, Br_2; b: C_2H_5OH / H^+; c: $LiAlH_4$; d: NaCN; e: TsCl / Py; f: diethyl acetamidomalonate, NH_3; g: PtO_2 / H_2; h: p-anisaldehyde, Et_3N; i: MPP; j: silica gel column; k: 6N HCl

cycloserine is derived from *O*-acetyl-L-serine and *N*-hydroxyurea,[15-17] we have reported[18] that ornithine (**3**) is the primary precursor of **1** and **2**, indicating a quite different biosynthesis.

We recognized that the first committed step toward the biosynthesis of **1** and **2** would most reasonably be hydroxylation of ornithine either at C-3 (the β-position) or at the terminal nitrogen (N^{δ}). Numerous naturally occurring β-hydroxyamino acids have been characterized,[19-25] but the formation of only one of these, *threo*-β-hydroxyaspartic acid, has been studied in detail.[26-29] β-Hydroxyornithine (**4**) has been synthesized a number of times,[30-32] but it has not yet been isolated as an authentic natural

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