The isolation and structure of a highly stable, metallation-resistant and multiply hydrogen-bonded sulfonylamide–phosphine oxide adduct, $PhSO_2CH_2C(=O)NH_2 \cdot O=P(NMe_2)_3$, PSA·HMPA (PSA = phenylsulfonylacetamide, HMPA = hexamethylphosphoramide)

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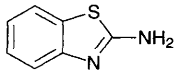
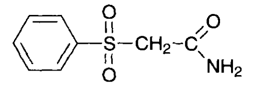
Attempted metallations of the expectedly acidic sulfonylamide (PSA) in the presence of the phosphine oxide HMPA all fail, giving instead the very stable 1:1 adduct PSA·HMPA; its solid-state structure consists of layers of PSA molecules linked by intercalated HMPA molecules, such aggregation resulting in particular from a large number of significant C–H···O hydrogen-bonding interactions per PSA·HMPA unit.

We reported earlier the first structurally characterised amine–phosphine oxide adduct, 2-aminobenzothiazole·HMPA [HMPA = $O=P(NMe_2)_3$].[1] Its essential unit consists of an amine base pair formed by two N–H···(heterocyclic)N hydrogen bonds of moderate strength and with the second H of each base's NH_2 group interacting rather more strongly with the O atom of an HMPA molecule. However, these $(base)_2 \cdot 2HMPA$ 'dimers' then link further by relatively weak (HMPA)O···H–C (of the C_6H_4 ring) interactions, so giving crystal packing involving [–base···HMPA···$(base)_2$···HMPA···base–] repeat units. Here we report the isolation and crystal structure of an adduct of HMPA with a sulfonylamide base, phenylsulfonylacetamide (PSA).



2-aminobenzothiazole



phenylsulfonylacetamide (PSA)

The 1 : 1 PSA·HMPA adduct, **1**, has a structure very different from that of the amine adduct. The introduction of SO_2, CH_2 and C=O units into the base allows base pairs themselves to aggregate, without the intermediacy of HMPA molecules. This is done by C–H···O hydrogen bonds. The resulting PSA layers are then linked by intercalated HMPA molecules, such linkage again relying in large part upon C–H···O interactions. The preponderance of these types of interaction, individually perhaps rather weak, but cumulatively significant on the macromolecular scale, serves to make **1** a seemingly unique system, and one of considerable interest in view of recent work on crystal engineering[2] and molecular recognition.[3]

Adduct **1** was first isolated fortuitously from the treatment of PSA with $\mathrm{Bu^nLi}$ and HMPA. Despite the fact that PSA seems to be a prime candidate for metallation, at the NH_2 group and/or at the CH_2 group, this could not be done in the presence of HMPA. Its treatment by reagents such as $\mathrm{Bu^tLi}$, MeLi and NaH in THF–HMPA media also gave **1** as the only isolable and high yield product. In retrospect, these findings bear testimony to the cumulative strength of the hydrogen bonds within **1**. Unsurprisingly, **1** was best prepared simply by dissolving PSA in toluene containing HMPA and then chilling the resulting solution. The ensuing crystals of **1** were characterised by elemental analyses and spectroscopic techniques,† and its solid-state structure was solved by X-ray diffraction.‡

In the structure of **1**, the striking feature is the number of hydrogen bonds, there being nine of these per PSA·HMPA molecular unit. The interactions can best be discussed in three sets and taking the convention that for X–H···O hydrogen bonds D is defined as the X···O distance and d as the H···O distance. The first set of interactions causes expected head-to-head base pairing of PSA molecules *via* $(N–H···O=C)_2$ eight-membered rings, with D = 2.947 Å and d = 2.101 Å (Fig. 1, central portion). The presence of SO_2, C=O, CH_2 and aryl CH units along the PSA molecule then prompts a second set of hydrogen bonds, all of type C–H···O. One PSA molecule of a given base pair links in a head-to-tail manner to a PSA molecule of a neighbouring base pair using two (aryl)C–H···O (of C=O) interactions (D = 3.266 Å, d = 2.459 Å) and two (methylene)C–H···O (of SO_2) interactions (D = 3.334 Å, d = 2.363 Å) (Fig. 1; Fig. 2, top and bottom layers). Cumulatively, these first two sets of hydrogen bonds lead to PSA layers comprising zigzag chains of PSA molecules.

Finally, these PSA layers are then linked together by adduct formation with the HMPA molecules *via* the third and final set of hydrogen bonds (Fig. 2). The O of a given HMPA molecule

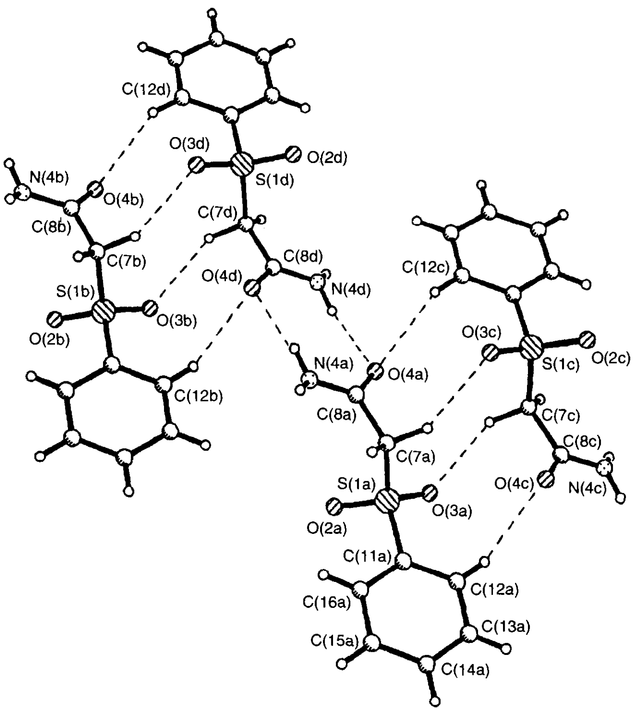


Fig. 1 The formation of PSA layers, involving base pairing and hydrogen-bond interactions between base pairs

interacts with the second amino hydrogen (that not used to effect head-to-head base pairing) of a PSA molecule (D = 2.823 Å, d = 2.182 Å); the N···O distance falls just outside the criterion suggested for a very strong N···O hydrogen bond (D = *ca.* 2.75 Å).[4] The same HMPA oxygen interacts also with the second methylene hydrogen (that not used to effect head-to-tail base pair aggregation) of the same PSA molecule (D = 3.294 Å, d = 2.563 Å). These two hydrogen bonds serve to join a given HMPA molecule to one PSA layer. The same HMPA contacts the adjacent PSA layer through a C–H···O interaction involving one of its methyl hydrogen atoms and the second sulfonyl oxygen (that not used in head-to-tail base-pair aggregation) of a PSA molecule (D = 3.480 Å, d = 2.560 Å). An especially neat aspect of these ···PSA···HMPA···PSA··· linkages is the way that, as noted, they allow usage of the remaining atoms along PSA molecules (the second O of SO_2, H of CH_2, H of NH_2), those not used for PSA aggregation. The four distinct hydrogen-bonding motifs can each be assigned a graph-set descriptor.[5] There are three distinct ring designators: $R^2_2(8)$ for N–H···O=C base pair, $R^2_2(9)$ for the C–H···O=C PSA head-to-tail linkages and $R^1_2(6)$ for the C–H···O=P adduct formation interactions. Finally, the designator D covers the HMPA methyl hydrogen to PSA sulfonyl oxygen interaction. The full graph-set description for **1** is $R^2_2(8)$, $R^2_2(9)$, $R^1_2(6)$, D.

The major feature of the structure of **1** is the *preponderance* of C–H···O hydrogen bonds within it; of the nine hydrogen bonds associated with each PSA·HMPA formula unit, six are of this type. A search of the Cambridge Crystallographic Database revealed only two structures having C–H···O interactions in any sense similar to those in **1**: a cyclopentadiene–thioaldehyde S-oxide adduct[6] and a thietan 1-oxide.[7] However, their hydrogen bondings are far less extensive than those in **1**. The *significance*, in structural and thermodynamic terms, of these C–H···O bonds is more difficult to assess. It has been suggested that the frequency with which such bonds occur implies an important role for them in determining organic crystal packing arrangements.[8] More quantitatively, proposed criteria for C–H···O interactions of significance cover a C···O distance of $3.0 < D < 4.0$ Å, with the mean distance D being 3.59 Å for 868 R_3CH···O contacts.[9] In these terms, the C–H···O contacts in **1** are short (range 3.266–3.480 Å, mean d = 3.329 Å). This study of **1** adds also a perhaps telling *reactivity* criterion, namely the failure to effect alkali metallation of acidic NH_2 or (even and especially) CH_2 units within its constituent PSA molecules. This is despite (or possibly partly because of) the presence of HMPA ligands, usually among the best stabilising complexants for alkali-metallated organics.[10] It is presumably a true irony that high acidity which usually encourages metallation can also encourage hydrogen bonding significant and extensive enough to prevent metallation, as seen here for **1**.

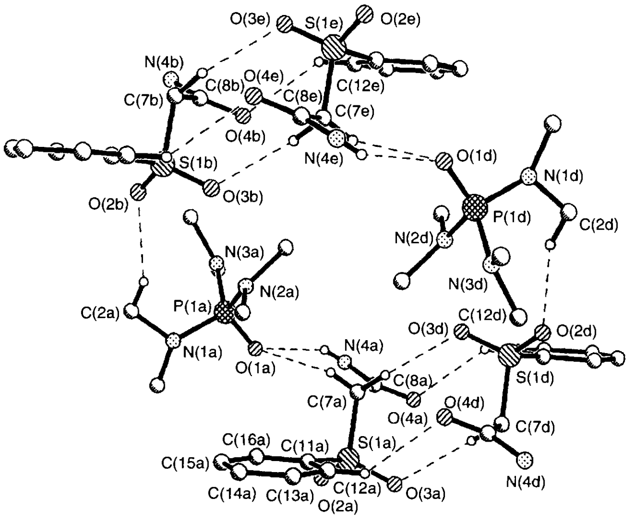


Fig. 2 Molecular structure of **1** showing the alternate layers of PSA and the intercalated HMPA molecules between them

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Footnotes

† *Experimental data* for **1**: phenylsulfonylacetamide, PSA, (0.996 g, 5 mmol) was added to a warm mixture of HMPA (4.5 ml, 25 mmol) and toluene (12 ml). After 5 min complete dissolution had occurred and the clear, colourless solution was refrigerated at −20 °C for 24 h, after which time colourless, crystalline rods of **1** were isolated. First batch yield: 1.47 g (78%), mp 80–84 °C. Elemental analysis: Found C, 44.3; H, 7.2; N, 14.8%; $C_{28}H_{54}N_8O_8P_2S_2$ requires C 44.4, H 7.1, N 14.8%. ^1H NMR {250 MHz, [$^2H_8$]THF, 293 K}: δ 7.9 (d), 7.6 (m, 5H, all Ar H), 4.7 [s, 2H, $PhSO_2CH_2C(O)NH_2$], 4.2 [s, 2H, $PhSO_2CH_2C(O)NH_2$], 2.6 [d, 18H, HMPA].

‡ *Crystal data* for **1**: $[PhSO_2CH_2C(O)NH_2{\cdot}HMPA]_2$: $C_{28}H_{54}N_8O_8P_2S_2$, M = 756.85, triclinic, space group $P\bar{1}$, a = 8.694(2), b = 9.360(2), c = 12.366(2) Å, α = 101.25(3), β = 96.48(3), γ = 97.44(3)°, U = 968.7(3) Å^3, F(000) = 404, λ(Mo-Kα) = 0.71073 Å, μ(Mo-Kα) = 0.274 mm^{-1}, T = 153(2)K, Z = 1, D_c = 1.297 Mg m^{-3}. Data were collected on a Stoe-Siemens diffractometer in the range $5° \leqslant 2\theta \leqslant 50°$ (3618 reflections collected, 3410 independent reflections). The structure was solved by direct methods[11] and refinement, based on F^2, was by full-matrix least-squares techniques[12] to R_1 = 0.0466, wR_2 = 0.1431 for 2997 unique data with [$F > 4\alpha(F)$]. In the final cycles of refinement all non-hydrogen atoms were assigned anisotropic displacement parameters. The N–H hydrogen atoms were located in the electron density map, and were refined freely with individual isotropic displacement parameters. The N-methyl hydrogen atoms were set up as rigid groups, with C–H 0.96 Å, and allowed to pivot about the C-atom to best fit the electron density map. All other hydrogen atoms were placed in idealised positions (C–H = 0.96 Å) and allowed to ride on the relevant C atoms.

Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre. See Information for Authors, Issue No. 1.

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