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Crystal and molecular structure of
diiodo-N,N,N',N'-tetramethylthiuramdisulphidemercury(II)

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Abstract

The crystal and molecular structure of diiodo-N,N,N',N'-tetramethylthiuramdisulphidemercury(II), HgI₂(S₂CN(CH₃)₂)₂, has been determined by a three-dimensional X-ray analysis. The compound crystallizes in the monoclinic space group $P2_1/c$ with the unit cell dimensions $a = 7.957 \pm 4$, $b = 22.639 \pm 7$, $c = 9.956 \pm 6$ Å and $\beta = 112.14 \pm 5^\circ$; $Z = 4$. Intensities were obtained with an automatic diffractometer. The structural parameters were refined by least-squares methods to a conventional $R$ factor of 0.044 for 1294 non-zero observed reflections. The mercury is in distorted tetrahedral coordination with two iodine and two sulphur atoms. The Hg—I distances are 2.654 ± 2 and 2.661 ± 2 Å; the Hg—S distances are 2.651 ± 7 and 2.882 ± 7 Å. The thiuramdisulphide ligand consists of two planar units S₂CNC₂, nearly perpendicular to each other. Bond distances of the ligand are compared with distances in tetraalkylthiuram disulphide molecules and agree with infrared observations.

Introduction

In preceding papers, the preparations and properties of diiodo-N,N,N',N'-tetrabutylthiuramdisulphidemercury(II) (Brinkhoff et al., 1969) and of the analogous ethyl derivative (Brinkhoff et al. 1970) were reported. The proposed molecular structure was confirmed by an X-ray analysis of the analogous methyl derivative, HgI₂(Me₄tds).

Crystal and intensity data

Diiodo-N,N,N',N'-tetramethylthiuramdisulphidemercury(II), HgI₂(S₂CN(CH₃)₂)₂, $FW = 694.87$, crystallizes in the space group $P2_1/c$ with the unit cell dimensions $a = 7.957 \pm 4$, $b = 22.639 \pm 7$, $c = 9.956 \pm 6$ Å, $\beta = 112.14 \pm 5^\circ$; $Z = 4$. The prismatic crystals are elongated along $a$. For practical reasons, the unconventional setting $B2_1/d$ was preferred (the transformation matrix to the conventional cell is $00\bar{1}/01\bar{0}/\bar{4}0\bar{1}$), with needle axis $c$, and the unit cell dimensions $a = 18.472 \pm 7$, $b = 22.639 \pm 7$, $c = 7.957 \pm 4$ Å and $\beta = 91.47 \pm 5^\circ$; $V = 3326 \pm 4$ Å³, $D_m = 2.76 \pm 3$ g cm⁻³ (pycnometer), $Z = 8$ and $D_x = 2.775 \pm 4$ g cm⁻³. Zirconium-filtered molybdenum radiation $\lambda$(Mo $K\alpha$) = 0.7107 Å was used. A crystal of approximately $0.06 \times 0.08 \times 0.38$ mm³ was mounted with the needle axis as rotation axis ($\phi$ axis). The systematic extinctions on Weissenberg and Precession photographs uniquely determined the space group. The cell dimensions were obtained by $\theta, \phi$ and $\chi$ measurements on a Nonius diffractometer; the cell dimensions with their estimated standard deviations are the result of a least-squares treatment of fifteen reflections in the range $10^\circ < \theta < 20^\circ$. 

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Intensity data were collected with an automatic Nonius diffractometer, using the moving counter-moving crystal method. Deviations from linearity of the scintillation counting equipment were less than 1%. The scan speed was 0.3°/min. Every 70 min, a reference reflexion was measured to detect fluctuations in the primary beam. Of the 3000 attainable symmetry-independent reflexions (up to $\sin \theta/\lambda = 0.595 \AA^{-1}$) 1294 reflexions have been measured above background and used for the structure determination. The intensities were corrected for fluctuations in the primary beam and for Lorentz and polarization effects. No absorption correction was applied ($\mu r_{\text{max}} = 0.5$; maximum effect upon the intensities: 13%).

**Determination of the structure**

The structure was solved by Patterson and Fourier methods; the positions of all atoms (except hydrogen) were located. After successful refinement with isotropic temperature factor parameters, the refinement was continued with anisotropic temperature parameters; the temperature factor was $\exp\left(-\left(h^2\beta_{11} + k^2\beta_{22} + l^2\beta_{33} + 2hk\beta_{23} + 2hl\beta_{31} + 2hk\beta_{12}\right)\right)$. Because of computer program limitations, the following two procedures were used in turn:

1. full-matrix refinement of one scale factor and positional and vibrational parameters of all mercury, iodine and sulphur atoms.

2. full-matrix refinement of the same scale factor and positional and vibrational parameters of all carbon and nitrogen atoms.

After three cycles (1 and 2), all shifts were negligible. The function minimized was $w(|F_o| - |F_c|)^2$, with the weight $w$ for each reflexion as obtained from counting statistics. The atomic scattering factors used were those of the neutral atoms corrected for anomalous scattering ($\Delta f'$), with data from the International Tables (1962). The final conventional $R$ factor is 0.044.

The final difference Fourier map showed some maxima of 0.7 eÅ$^{-3}$ around the mercury position, and on the mercury position a minimum of about $-0.5$ eÅ$^{-3}$. At distances varying from 0.7 to 1.5 Å to the methylcarbon positions, a number of maxima of height 0.3-0.5 eÅ$^{-3}$ were found but none of these could be interpreted clearly as hydrogen.

Calculations were performed on an IBM 360/50 computer, using programs written by Busing et al. (1962), Pippy & Ahmed (1967), Beurskens et al. (1969) and Beurskens (1968).

**Description of the molecule**

The atomic parameters are given in table 1, and the structure is illustrated in Fig. 1. Bond distances and angles are given in Fig. 2; the shortest S–S van der Waals contact is 3.78(1) Å.

The coordination of mercury is shown in Fig. 3. The mercury atom is equidistant to the two iodine and the S(1) atoms (2.66 Å), and is only 0.305 ± 1 Å out of the plane of these three atoms. The Hg–S(4) bond (2.88 Å) is significantly longer and nearly perpendicular (84°) to this plane. A similar geometry was found in the compound $[\text{S(CH}_3)_2\text{HgI}_4]_n$ (Fenn, 1966), with three Hg–I bonds of 2.70 Å (average) and one Hg–I bond of 2.80 Å. The Hg–S(4) distances in other tetrahedrally coordinated mercury compounds are, for example, 2.33 Å in HgS (metacinnabar) (Aurivillius, 1950) and 2.61 Å in HgCl$_2$-1,3,5-trithian (Costello et al., 1966). The S–Hg–S and I–Hg–I angles agree within 3° with the relationship between coordination angles given by Cheung & Sim (1965).

The thiuramdisulphide ligand contains two planar groups S$_2$CNC$_2$. The equation of the least squares plane through S(1)S(2)C(1)N(1)C(3)C(4) is

$$0.0308X + 0.5997Y + 0.7997Z - 0.3465 = 0$$

with the deviations from the plane

<table>
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<tr>
<th>Atom</th>
<th>Deviation</th>
</tr>
</thead>
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<tr>
<td>S(1)</td>
<td>-0.003(7)</td>
</tr>
<tr>
<td>S(2)</td>
<td>0.005(7)</td>
</tr>
<tr>
<td>C(1)</td>
<td>-0.03(2)</td>
</tr>
<tr>
<td>N(1)</td>
<td>-0.01(2)</td>
</tr>
<tr>
<td>C(3)</td>
<td>-0.04(2)</td>
</tr>
<tr>
<td>C(4)</td>
<td>0.08(2)</td>
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Table 1. Atomic parameters for HgI₂(Me₄tds) and standard deviations

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>β₁₁</th>
<th>β₂₂</th>
<th>β₃₃</th>
<th>β₁₂</th>
<th>β₁₃</th>
<th>β₂₃</th>
<th>β₃₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>0.0703(1)</td>
<td>0.1690(1)</td>
<td>0.1030(2)</td>
<td>0.0035(1)</td>
<td>0.0020(1)</td>
<td>0.0198(3)</td>
<td>0.0004(1)</td>
<td>0.0022(1)</td>
<td>0.0009(1)</td>
<td></td>
</tr>
<tr>
<td>I(1)</td>
<td>-0.0418(1)</td>
<td>0.1271(1)</td>
<td>0.2697(3)</td>
<td>0.0032(1)</td>
<td>0.0033(1)</td>
<td>0.0247(6)</td>
<td>0.0011(1)</td>
<td>0.0014(2)</td>
<td>0.0025(1)</td>
<td></td>
</tr>
<tr>
<td>I(2)</td>
<td>0.1487(1)</td>
<td>0.2660(1)</td>
<td>0.0627(3)</td>
<td>0.0051(1)</td>
<td>0.0019(1)</td>
<td>0.0272(6)</td>
<td>0.0008(1)</td>
<td>0.0009(2)</td>
<td>0.0008(1)</td>
<td></td>
</tr>
<tr>
<td>S(1)</td>
<td>0.0703(3)</td>
<td>0.1079(3)</td>
<td>-0.1776(9)</td>
<td>0.0026(2)</td>
<td>0.0031(2)</td>
<td>0.0170(18)</td>
<td>0.0003(2)</td>
<td>0.0001(6)</td>
<td>0.0021(5)</td>
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<tr>
<td>S(2)</td>
<td>0.2306(3)</td>
<td>0.0795(3)</td>
<td>-0.1370(9)</td>
<td>0.0029(3)</td>
<td>0.0033(2)</td>
<td>0.0216(20)</td>
<td>0.0007(2)</td>
<td>0.0007(6)</td>
<td>0.0017(5)</td>
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<tr>
<td>S(3)</td>
<td>0.1817(4)</td>
<td>0.0106(3)</td>
<td>-0.0241(10)</td>
<td>0.0056(3)</td>
<td>0.0019(2)</td>
<td>0.0210(21)</td>
<td>0.0007(2)</td>
<td>0.0012(7)</td>
<td>0.0004(5)</td>
<td></td>
</tr>
<tr>
<td>S(4)</td>
<td>0.1896(3)</td>
<td>0.1038(3)</td>
<td>0.2520(9)</td>
<td>0.0035(3)</td>
<td>0.0019(2)</td>
<td>0.0200(19)</td>
<td>0.0001(2)</td>
<td>0.0034(6)</td>
<td>0.0002(5)</td>
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</tr>
<tr>
<td>C(1)</td>
<td>0.1579(10)</td>
<td>0.1242(9)</td>
<td>-0.2202(28)</td>
<td>0.0019(8)</td>
<td>0.0022(6)</td>
<td>0.0061(56)</td>
<td>0.0001(6)</td>
<td>0.0017(18)</td>
<td>0.0028(16)</td>
<td></td>
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<tr>
<td>C(2)</td>
<td>0.1786(9)</td>
<td>0.1684(8)</td>
<td>-0.3188(23)</td>
<td>0.0036(8)</td>
<td>0.0015(4)</td>
<td>0.0126(49)</td>
<td>0.0018(6)</td>
<td>0.0016(16)</td>
<td>0.0012(14)</td>
<td></td>
</tr>
<tr>
<td>C(3)</td>
<td>0.1662(11)</td>
<td>0.0328(10)</td>
<td>0.1949(28)</td>
<td>0.0025(9)</td>
<td>0.0026(7)</td>
<td>0.0037(60)</td>
<td>0.0014(7)</td>
<td>0.0002(19)</td>
<td>0.0018(16)</td>
<td></td>
</tr>
<tr>
<td>C(4)</td>
<td>0.1314(9)</td>
<td>-0.0046(10)</td>
<td>0.2809(28)</td>
<td>0.0016(7)</td>
<td>0.0034(7)</td>
<td>0.0148(57)</td>
<td>0.0004(6)</td>
<td>0.0012(17)</td>
<td>0.0048(18)</td>
<td></td>
</tr>
<tr>
<td>C(5)</td>
<td>0.2536(12)</td>
<td>0.1866(10)</td>
<td>-0.3473(28)</td>
<td>0.0036(10)</td>
<td>0.0026(8)</td>
<td>0.0139(63)</td>
<td>0.0016(7)</td>
<td>0.0033(21)</td>
<td>0.0012(17)</td>
<td></td>
</tr>
<tr>
<td>C(6)</td>
<td>0.1173(12)</td>
<td>0.2051(11)</td>
<td>-0.4105(33)</td>
<td>0.0046(11)</td>
<td>0.0022(7)</td>
<td>0.0302(79)</td>
<td>0.0030(7)</td>
<td>-0.0061(25)</td>
<td>-0.0017(18)</td>
<td></td>
</tr>
</tbody>
</table>

The key to the atomic numbering is given in Figure 2. The general positions for space group B2₁/d are: (0,0,0; ½,0,½) ± (x,y,z; ½ + x, ½ - y, ¼ + z). The positions for the P2₁/c setting are given by the transformation matrix 101/010/200.
Fig. 1. Projection of HgI$_2$(Me$_4$tds) on (101).

Fig. 2. Bond distances and angles in HgI$_2$(Me$_4$tds) and standard deviations. The bond angles I$_1$—Hg—S$_4$(102·1 ± 2°) and I$_1$—Hg—S$_1$(109·4 ± 2°) are not given in the figure.
The plane through S(3)S(4)C(2)N(2)C(5)C(6) is given by
\[
0.8852X - 0.3523Y + 0.3038Z - 2.8330 = 0
\]

with the deviations from the plane
\[
\begin{align*}
S(3): & \quad 0.001(7) \\
N(2): & \quad 0.02(2) \\
S(4): & \quad 0.002(7) \\
C(5): & \quad -0.03(2) \\
C(2): & \quad -0.06(2) \\
C(6): & \quad 0.06(2)
\end{align*}
\]

The dihedral angle between these planes is 86.6°. The atom S(2) is situated in both planes, and the dihedral C—S—S—C angle is 89.2°.

In Table 2, the geometry of the thiuramdisulphide ligand in HgI₂(Me₄tds), is compared with the geometry of tetramethylthiuramdisulphide (Me₄tds) (Maray, 1965) and tetrathytiuramdisulphide (Et₄tds) (Karle, Estlin and Britts, 1967). The observed C—N distances are not conclusive with respect to the increase of the C—N bond order as indicated by infrared and nmr measurements. The difference in the C—S distances agree with the infrared spectra (Brinkhoff et al., 1970).

Table 2. Comparison of the geometry in thiuramdisulphide

<table>
<thead>
<tr>
<th></th>
<th>HgI₂(Me₄tds)</th>
<th>Me₄tds</th>
<th>Et₄tds</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(1)—N(1), C(2)—N(2)</td>
<td>1.27, 1.32 Å</td>
<td>1.31 Å</td>
<td>1.33, 1.36 Å</td>
</tr>
<tr>
<td>C(1)—S(1), C(2)—S(4)*</td>
<td>1.71, 1.72 Å</td>
<td>1.61 Å</td>
<td>1.66, 1.63 Å</td>
</tr>
<tr>
<td>S(2)—S(3)</td>
<td>2.03 Å</td>
<td>2.00 Å</td>
<td>2.00 Å</td>
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<tr>
<td>Dihedral C(1)—S(2)—S(3)—C(2) angle</td>
<td>89.2°</td>
<td>88°</td>
<td>96.4°</td>
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</table>

* C=S bond in Me₄tds and Et₄tds.

The authors are grateful to Professor J. J. Steggerda for his continuous interest, and to Mr W. P. J. H. Bosman and Mr J. M. M. Smits for valuable assistance.

References

Pippy, M. E. & Ahmed, F. R. (1967) *Scan of Interatomic Distances and Angles (NRC-12), Mean Plane (NRC-22).*

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