Refinement of Tetrachlorophthalic Anhydride and Tetrabromophthalic Anhydride

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Abstract

The isostructural title compounds, $C_8X_4O_3$ [where $X =$ Cl (TCPA) and Br (TBPA)], are monoclinic, $P2_1/n$, $Z = 4$. At 293 K the crystal data are: TCPA: $a = 13\cdot438$ (1), $b = 5\cdot7874$ (4), $c = 12\cdot332$ (1) Å, $\beta = 91\cdot182$ (3)°, $D_x = 1\cdot98$ Mg m^{-3}, $V = 958\cdot9$ Å^3, μ(Cu $K\alpha) = 11\cdot10$ mm^{-1}. The known structure was refined by full-matrix least squares to a conventional $R = 0\cdot033$ for 1615 independent reflections; TBPA: $a = 13\cdot422$ (3), $b = 6\cdot1794$ (14), $c = 12\cdot680$ (3) Å, $\beta = 90\cdot789$ (7)°, $D_x = 2\cdot93$ Mg m^{-3}, $V = 1051\cdot6$ Å^3, μ(Cu $K\alpha) = 20\cdot74$ mm^{-1}. The known structure was refined by full-matrix least squares to a conventional $R = 0\cdot042$ for 1778 independent reflections. In both molecules, chemically equivalent but crystallographically unique bond lengths are equal, the benzene ring is slightly distorted, and the molecule is non-planar (the halogen atoms are out of the molecular plane and the plane of the benzene ring is inclined to the plane of the five-membered heterocyclic ring). In TCPA the C—Cl bond lengths agree with the observation of Rudman [*Acta Cryst.* (1971), B**27**, 262–269], as modified by Herbstein [*Acta Cryst.* (1979), B**35**, 1661–1670].

Introduction

The tetrahalophthalic anhydride (TXPA) compounds, $C_6X_4(CO)_2O$, where $X =$ F (TFPA), Cl (TCPA), Br (TBPA), or I (TIPA), have been studied extensively in recent years. Theoretically, the molecules should be planar, but the overcrowding around the benzene ring by the halogen atoms results in molecular distortion. Also, the TXPA compounds are known to form charge-transfer complexes with a number of polycyclic compounds (*e.g.* Wilkerson, Chodak & Strouse, 1975). It is advisable to determine the structures of the uncomplexed TXPA molecules so that the effect of any complex formation can be recognized.

TCPA and TBPA, which are isostructural at room temperature, were originally studied using film data. The TCPA investigation (Rudman, 1971) resulted in e.s.d.'s of up to 0·02 Å in bond lengths and 2° in bond angles with apparently significant differences in chemically equivalent but crystallographically unique molecular parameters. An analysis of TCPA and similar compounds revealed that the mean C—Cl length was 1·709 Å when the compound contained two or more *ortho* C—Cl bonds and 1·737 Å when the compound contained isolated C—Cl bonds. A subsequent low-temperature crystal structure analysis of the 1:1 naphthalene–TCPA complex showed that the chemically equivalent molecular parameters in TCPA are similar (Wilkerson, Chodak & Strouse, 1975), while a reappraisal of more recent data indicated that the length of *ortho* C—Cl bonds is closer to 1·717 Å (uncorrected) and 1·721 Å (with a rough correction for thermal motion) (Herbstein, 1979). The structure of TBPA (Ito, Moriya, Kashino & Haisa, 1975) was based on data collected on a 0·08 × 1·1 × 0·05 mm crystal and uncorrected for absorption effects. E.s.d.'s of up to 0·04 Å in bond lengths and 2° in bond angles with apparently significant differences in chemically equivalent but crystallographically unique molecular parameters were observed.

The present refinements were undertaken to clarify these results and were accompanied by investigations of TFPA and TIPA. Our preliminary investigation of TFPA revealed that it crystallizes in a triclinic cell with eight molecules per unit cell. The structure of TIPA, which crystallizes in the tetragonal space group $I4_1/a$ with 16 molecules per unit cell, is reported elsewhere (Sake Gowda & Rudman, 1982).

Data collection and refinement

TCPA

A 0·09 × 0·11 × 0·13 mm crystal grown by sublimation for the earlier study of TCPA was mounted on a Syntex $P2_1$-F diffractometer and accurate unit-cell parameters (given in the *Abstract*) were obtained from a least-squares refinement of 20 carefully centered reflections. 3429 reflections ($2\theta_{max} = 135°$, Ni-filtered Cu K radiation, $\lambda = 1\cdot54051$ Å) were measured using the θ–2θ scan mode, from which 1715 independent reflections were obtained. The crystal was

automatically recentered every 438 reflections, with 6 standard reflections examined after each 102 measurements. Empirical absorption (based on 13 ψ scans) and Lorentz–polarization corrections were applied, but no decay corrections were necessary. The data were refined using full-matrix least-squares analysis of 1615 reflections with $F > 2\sigma(F)$.

TBPA

A $0.08 \times 0.08 \times 0.16$ mm crystal grown from a benzene–toluene solution was mounted on a Syntex $P2_1$-F diffractometer and accurate unit-cell parameters (see Abstract) were obtained from a least-squares refinement of 20 carefully centered reflections. 3781 reflections ($2\theta_{max} = 135°$, Ni-filtered Cu K radiation, $\lambda = 1.54051$ Å) were measured using the θ–2θ scan mode, from which 1881 independent reflections were obtained. The crystal was automatically recentered as for TCPA. Empirical absorption (based on 16 ψ scans) and Lorentz–polarization corrections were applied but decay corrections were not necessary. The data were

Table 1. *Fractional coordinates* ($\times 10^5$) *and* B_{eq} *values with e.s.d.'s in parentheses*

$$B_{eq} = \tfrac{1}{3} \sum_i \sum_j B_{ij} a_i^* a_j^* \mathbf{a}_i . \mathbf{a}_j.$$

	x	y	z	B_{eq} (Å^2)
TCPA				
Cl(1)	12126 (4)	8951 (11)	57273 (5)	3.75 (3)
Cl(2)	32452 (5)	18827 (12)	69402 (5)	4.08 (3)
Cl(3)	45255 (4)	60758 (12)	62993 (5)	4.19 (4)
Cl(4)	38888 (5)	91641 (12)	43106 (5)	4.12 (3)
O(1)	8385 (12)	65260 (33)	31224 (13)	3.77 (9)
O(2)	290 (14)	35009 (37)	38222 (16)	4.62 (10)
O(3)	19322 (15)	93781 (39)	28154 (15)	4.69 (10)
C(1)	16642 (15)	46447 (38)	45221 (16)	2.56 (9)
C(2)	19414 (16)	31807 (37)	53599 (17)	2.64 (9)
C(3)	28523 (16)	36329 (38)	58980 (16)	2.62 (9)
C(4)	34433 (16)	55045 (40)	55936 (17)	2.80 (9)
C(5)	31588 (15)	69320 (38)	47264 (17)	2.65 (9)
C(6)	22525 (15)	64658 (38)	42139 (16)	2.57 (9)
C(7)	17289 (17)	76899 (45)	33130 (18)	3.26 (11)
C(8)	7494 (16)	46790 (45)	38275 (18)	3.24 (11)
TBPA				
Br(1)	11768 (4)	8067 (10)	56708 (5)	3.51 (3)
Br(2)	32765 (5)	19396 (10)	69599 (5)	3.50 (3)
Br(3)	45606 (4)	62153 (11)	63315 (5)	3.63 (3)
Br(4)	38817 (5)	91400 (11)	42518 (5)	3.92 (4)
O(1)	8201 (30)	62622 (75)	31225 (32)	3.71 (22)
O(2)	167 (36)	34713 (90)	38463 (38)	4.58 (25)
O(3)	19191 (37)	89012 (91)	27710 (36)	5.02 (28)
C(1)	16535 (36)	45713 (92)	44795 (40)	2.58 (23)
C(2)	19537 (38)	32232 (87)	53122 (40)	2.45 (20)
C(3)	28451 (38)	37148 (88)	58477 (38)	2.57 (22)
C(4)	34147 (37)	54824 (90)	55662 (39)	2.49 (22)
C(5)	31196 (40)	67930 (88)	46979 (42)	2.58 (20)
C(6)	22284 (38)	62775 (89)	41811 (37)	2.54 (23)
C(7)	17147 (42)	37811 (107)	32971 (47)	3.27 (26)
C(8)	7372 (41)	45852 (105)	38380 (43)	3.17 (26)

refined using full-matrix least-squares analysis of 1778 reflections with $F > 2\sigma(F)$.

In the final least-squares cycle, 136 parameters were varied (nine per atom, one scale factor), with convergence attained when the maximum shift/error was less than 0.005. The final unweighted and weighted residuals [$R = \sum |\Delta F| / \sum |F_o|$; $R_w = (\sum w |\Delta F|^2 / \sum w |F_o|^2)^{1/2}$] for TCPA were 0.033 and 0.052 for the 1615 reflections and 0.035 and 0.053 when the 'unobserved' data were included; $S = 1.149$. For TBPA $R = 0.042$ and $R_w = 0.061$ for 1778 reflections, with $R = 0.046$ when all data were included; $S = 1.368$. The function minimized was $\sum w(|F_o| - |F_c|)^2$, with $w^{-1} = \sigma^2(F) + (0.040 F_o)^2$, where $\sigma(F_o)$ is based on counting statistics. All calculations were performed using the Syntex XTL programs (which utilize atomic scattering factors based on the analytical expressions found in International Tables for X-ray Crystallography, 1974) with the exception of the rigid-body calculations that were carried out using TLS6 (Schomaker & Trueblood, 1968). Anomalous-dispersion corrections for the halogen atoms were included. The final fractional coordinates and equivalent isotropic thermal parameters are listed in Table 1.*

The final difference Fourier map for TCPA was featureless, while that for TBPA had some residual electron density near the Br-atom positions.

Discussion

The data in Table 2, following the labelling system shown in Fig. 1, show that, within the limits of

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* Lists of structure factors, anisotropic thermal parameters, and rigid-body tensors, and tables of the least-squares planes and the ORTEP diagram of the TBPA molecule have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 36959 (31 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.
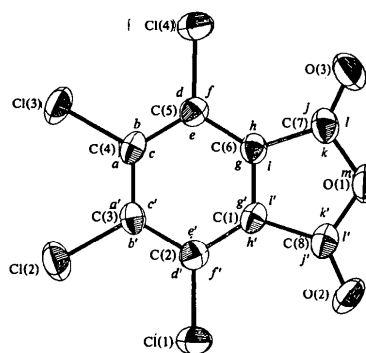

Fig. 1. An ORTEP drawing (Johnson, 1965) of the TCPA molecule with the thermal ellipsoids scaled at the 50% probability level. The letter symbols refer to the angles whose values are given in Table 2. (The TBPA diagram has been deposited.)

Table 2. Intramolecular interatomic distances (Å) and angles (°)

The corrected values are based on a rigid-body treatment (Schomaker & Trueblood, 1968); the angles are identified by the primed and unprimed letter symbols in Fig. 1.

	TCPA (X = Cl)		TBPA (X = Br)	
	Uncor-rected	Corrected	Uncor-rected	Corrected
Distances				
X(1)–C(2)	1·713 (2)	1·720	1·881 (5)	1·888
X(2)–C(3)	1·711 (2)	1·718	1·872 (5)	1·879
X(3)–C(4)	1·712 (2)	1·719	1·863 (5)	1·870
X(4)–C(5)	1·707 (2)	1·717	1·867 (5)	1·874
Average	1·711	1·719	1·871	1·878
C(7)–O(1)	1·389 (3)	1·395	1·401 (7)	1·406
C(8)–O(1)	1·385 (3)	1·391	1·383 (8)	1·388
C(7)–O(3)	1·189 (3)	1·194	1·186 (8)	1·191
C(8)–O(2)	1·184 (3)	1·189	1·187 (8)	1·192
C(1)–C(8)	1·484 (3)	1·490	1·465 (7)	1·471
C(6)–C(7)	1·483 (3)	1·489	1·475 (8)	1·480
C(1)–C(2)	1·381 (3)	1·387	1·400 (9)	1·405
C(2)–C(3)	1·405 (3)	1·411	1·401 (7)	1·406
C(3)–C(4)	1·399 (3)	1·405	1·383 (8)	1·388
C(4)–C(5)	1·398 (3)	1·405	1·419 (7)	1·424
C(5)–C(6)	1·387 (3)	1·390	1·393 (7)	1·398
C(6)–C(1)	1·376 (3)	1·382	1·363 (8)	1·369
X(1)···X(2)	3·139 (1)	3·153	3·313 (1)	3·326
X(2)···X(3)	3·087 (1)	3·101	3·259 (1)	3·272
X(3)···X(4)	3·139 (1)	3·152	3·314 (1)	3·327
Angles (x)	x	x'	x	x'
a,a'	119·6 (2)	119·5 (2)	120·9 (4)	119·4 (4)
b,b'	119·4 (2)	119·8 (2)	119·0 (4)	119·4 (4)
c,c'	121·0 (2)	120·8 (2)	120·1 (4)	121·2 (5)
d,d'	121·8 (2)	121·1 (2)	122·0 (4)	121·9 (4)
e,e'	117·2 (2)	117·3 (2)	117·6 (5)	118·1 (5)
f,f'	121·0 (2)	121·7 (2)	120·4 (4)	120·0 (4)
g,g'	121·8 (2)	121·9 (2)	122·1 (5)	120·8 (5)
h,h'	130·3 (2)	130·4 (2)	129·9 (5)	130·8 (5)
i,i'	107·8 (2)	107·7 (2)	108·0 (5)	108·4 (5)
j,j'	132·0 (2)	131·5 (2)	133·2 (6)	132·0 (6)
k,k'	106·8 (2)	107·0 (2)	106·4 (5)	107·1 (5)
l,l'	121·2 (2)	121·5 (2)	120·4 (6)	120·9 (6)
m	110·7 (2)		110·1 (5)	

experimental error (e.s.d.'s of 0·003 Å in bond lengths and 0·2° in bond angles for TCPA, and 0·009 Å and 0·5° for TBPA), the TCPA and TBPA molecules have pseudomirror planes perpendicular to the planes of the molecules. The mirror symmetry is destroyed by the deviations of the halogen atoms from the plane of the benzene ring (Table 3).

The presence of the fused heterocyclic five-membered ring results in a slight distortion of the benzene ring. Similar distortions of the benzene ring were observed in TIPA (Sake Gowda & Rudman, 1982), and phthalic anhydride (Bates & Cutler, 1977); but were not observed in 5-ethyl-2-methylpyridinium tetrachlorophthalate (Galloy, Putzeys, Germain & Van Meerssche, 1976) or tetrachlorophthalic hemi-

Table 3. Equations for and deviations ($\times 10^4$ Å) of atoms from the weighted least-squares planes in the TXPA molecules (x, y, z in Å)

TCPA: $0·4819x - 0·5949y - 0·6433z + 4·1591 = 0$
TBPA: $0·5098x - 0·5855y - 0·6303z + 4·1288 = 0$

	TCPA (X = Cl)	TBPA (X = Br)
X(1)*	228 (6)	603 (6)
X(2)*	221 (6)	458 (6)
X(3)*	−763 (6)	−1148 (6)
X(4)*	500 (6)	427 (6)
C(1)	−49 (21)	−130 (53)
C(2)	39 (21)	73 (52)
C(3)	45 (21)	68 (51)
C(4)	−119 (22)	−155 (52)
C(5)	109 (21)	99 (54)
C(6)	−26 (21)	42 (51)

* Atom not included in the calculation of the least-squares plane.

hydrate (Ito, Moriya, Kashino & Haisa, 1975), which do not have five-membered rings fused to their benzene rings.

The general structural features reported in the original investigation of TCPA (Rudman, 1971) are corroborated, with three Cl atoms above and one Cl atom below the plane of the benzene ring and with the six-membered and five-membered rings inclined to each other at an angle of 1·49°. In TBPA they are inclined at an angle of 3·15°. The C—O distances are similar in both compounds and agree with those observed in TIPA but differ significantly from those reported by Ito et al. (1975) for TBPA.

The C—Br distances, in TBPA, are similar to those reported in other polybrominated aromatic compounds, e.g. 1·880–1·904 (18) Å in 1,2,4,5-tetrabromobenzene (Gafner & Herbstein, 1960), 1·879–1·881 (5) Å in tetrabromo-p-phenylene bis(toluene-p-sulphonate) (Wieczorek, 1980), and 1·870 (7) Å in a bromanil complex (Mayerle & Torrance, 1981). Most other reports of C—Br distances in polybrominated compounds have large e.s.d.'s.

In TCPA, the average C—Cl distances (Table 2) agree with Herbstein's (1979) average values (quoted above) and are significantly shorter than the distances observed in isolated C—Cl bonds.

The possibility of polymorphism in the tetrahalophthalic anhydrides arose for reasons to be discussed elsewhere (Sake Gowda & Rudman, 1982). A differential scanning calorimetry thermogram of TCPA revealed that a high-temperature phase forms as the melt is cooled, but it was not possible to grow a single crystal of this phase. This agrees with McCrone's (1951) observation that an unstable polymorph can be grown from the melt. The high-temperature investigation of TBPA is in progress.

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The Structure of Tetrazole Steroid Analogues.
II.* The Structure of 3,6-Diaza-*A*,*B*-bishomocholest-4a-eno[3,4-*d*][6,7-*d*]bistetrazole (HS-650) Monohydrate

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Abstract

The crystal structure of a bistetrazolo steroid (HS-650) in the form of its aqueous solvate, $C_{27}H_{42}N_8.H_2O$, has been determined by direct methods. The crystals are orthorhombic, $P2_12_12_1$, with $a = 9.025$ (1), $b = 12.776$ (1), $c = 50.253$ (4) Å, $Z = 8$, $D_m = 1.134$ (3), $D_x = 1.138$ Mg m^{-3}. Anisotropic least-squares refinement by cascade matrices led to the residual value $R = 0.087$ for a total of 6185 unique reflections [$R = 0.065$ for 4456 reflections, $I > 3\sigma(I)$]. The fusion of tetrazole groups to rings *A* and *B* of the steroid has produced strains in the rings resulting in an overall *cis* conformation. A computer-graphics picture system was used to show the disorder associated with high thermal parameters, observed in the cholesteryl side chains of both molecules. Solvent water molecules hydrogen-bond with tetrazole groups to form continuous sheets parallel to (001). The two molecules in the asymmetric unit are related by a pseudo twofold axis approximately parallel to [010] and the crystal packing consequently shows pseudo $C222_1$ symmetry.

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Introduction

As part of a study of the synthesis of tetrazolo steroids 3,6-diaza-*A*,*B*-bishomocholest-4a-eno[3,4-*d*][6,7-*d*]bistetrazole (HS-650) and 4,6-diaza-*A*,*B*-bishomo-4a-eno-[4,3-*d*][6,7-*d*]bistetrazole (HS-649) (Fig. 1) were produced when cholest-4-ene-3,6-dione was treated with excess of hydrazoic acid and boron trifluoride in benzene (Singh, Butani, Malhotra & Paul, 1978). Although tetrazoles are metabolically stable the chemical and structural changes produced by introduction of such groups into steroids may affect the course of drug action. The work described here and in a following paper was undertaken in order to ascertain the chemical structures and to characterize important features of the molecular geometry of these two compounds.