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2,3,7,8-Tetrachlorodibenzofuran*

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Abstract. $C_{12}H_4Cl_4O$, $M_r = 305.97$, monoclinic, $C2/c$, $a = 14.702$ (4), $b = 12.886$ (4), $c = 6.256$ (1) Å, $\beta = 99.90$ (2)°, $V = 1168$ Å³, $\rho_{obs} = 1.72$ (floatation), $\rho_{calc} = 1.74$ g cm⁻³, $Z = 4$. The structure has been determined by direct methods and refined to $R = 0.042$ for 1863 independent reflections. The molecule is essentially planar. A crystallographic twofold axis bisects a C–C bond and passes through the O atom of the five-membered furan ring. The two unique C–Cl distances are 1.725 (2) and 1.732 (2) Å, the C–O distance is 1.385 (2) Å, and the benzenoid ring C–C distances range between 1.366 (2) and 1.404 (2) Å. The longest C–C bond distance within the benzenoid rings joins the C atoms to which the Cl atoms are attached. The title compound is closely related in structure to the highly toxic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin.

Introduction. Chlorinated dibenzofurans have recently been recognized as significant contaminants in some industrial chemicals; 2,3,7,8-tetrachlorodibenzofuran (TCDBF; Fig. 1a) has been reported to be

extremely active biologically (see *Discussion* for references). This specific tetrachloro isomer was synthesized under an FDA-supported contract by Gray, Dipinto & Solomon (1976). Crystals of the compound suitable for structural analysis were crystallized from 2,2,4-trimethylpentane ('iso-octane'; distilled in glass) by one of us (IHP) and dried with paraffin under vacuum. The space group $C2/c$ was confirmed by a successful refinement; no calculations were made

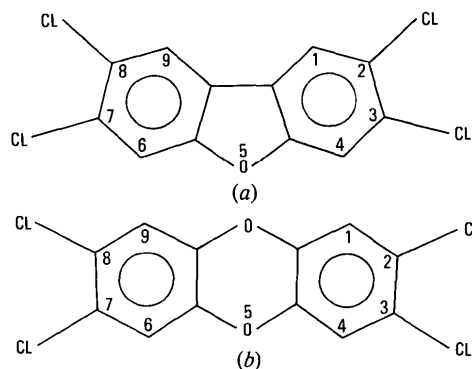


Fig. 1. Molecular structures of (a) 2,3,7,8-tetrachlorodibenzofuran and (b) 2,3,7,8-tetrachlorodibenzo-*p*-dioxin.

* Named in accordance with the accepted system of organic chemical nomenclature. Because of the crystallographic twofold axis in the molecule, the labeling of the atoms in the figures (except Fig. 1) and tables of this paper is shown as 3,4,3',4'-tetrachlorodibenzofuran.

in the noncentrosymmetric space group *Cc*. Density (floatation) was consistent with $C_{12}H_4Cl_4O$ and $Z = 4$.

A colorless approximately ellipsoidal crystal ($0.062 \times 0.018 \times 0.021$ cm) was mounted for data collection. No attempt was made to obtain a smaller or more regular crystal by cutting, grinding, or dissolving because of the hazardous nature of the material and because of the existence of only several crystals. As the crystal used had a relatively small μR ($\mu = 89.8 \text{ cm}^{-1}$ for Mo $K\alpha$) and was too irregular (no well defined planes) to measure, no absorption correction was applied. Cell parameters were obtained from a least-squares fit of 15 reflections using Mo $K\alpha$ radiation ($\lambda = 0.71069 \text{ \AA}$). 1863 unique reflections were measured on an automated four-circle diffractometer out to $\theta = 30.06^\circ$ using the bisecting mode, θ - 2θ scans, and Mo $K\alpha$ radiation ($\lambda = 0.71069 \text{ \AA}$), which was monochromated with a pyrolytic graphite crystal. Four reflections, measured periodically, showed no significant decrease in intensity during data collection. The data were corrected for Lorentz and polarization effects.

The trial model (all atoms except H) was obtained using *MULTAN* (Germain, Main & Woolfson, 1971). The sequence of trial model, isotropic refinement, difference map, and anisotropic refinement proceeded smoothly. The two H positions on the benzenoid ring were calculated assuming H-C-C angles of 120° , planarity of the ring, and a bond length of 1 \AA .

The weighting scheme applied was based on counting statistics combined with an instrumental instability factor derived from the four check reflections. The weights were $1/\sigma(F)^2$ where $\sigma(F) = [F^2 + \sigma(I)/Lp]^{1/2} - F$ and $\sigma(I)^2 = (\text{total counts}) + (0.85 \times 10^{-4})(\text{total counts})^2$. All 1863 unique reflections were used in the least-squares refinements. The scattering factors for H were taken from Stewart, Davidson & Simpson (1965); the scattering factors for C, O, and Cl were computed from numerical Hartree-Fock wave functions (Cromer & Mann, 1968). Anomalous-dispersion factors f' and f'' for Cl atoms were from *International Tables for X-ray Crystallography* (1974). The computer programs used were from XRAY 76 (Stewart, Machin, Dickinson, Ammon, Heck & Flack, 1976).

The model was refined to a conventional R , based on F , of 0.042 and a weighted R_w of 0.039 $\{R_w = [\sum w(|F_o| - |F_c|)^2 / \sum wF_o^2]^{1/2}$; function minimized: $\sum w(|F_o| - |F_c|)^2$ with $w = [\sigma(F_o)]^{-2}$. The average and the maximum shift/error were 0.005 and 0.01 respectively. An analysis of the difference map showed no peak greater than 0.24 e \AA^{-3} . Table 1 lists the final atomic parameters.*

* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 33459 (16 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 1. *The final positional parameters with their standard deviations in parentheses*

	x	y	z
C(1)	0.5431 (1)	0.6598 (1)	1.1218 (2)
C(2)	0.5937 (1)	0.6262 (1)	0.9714 (3)
C(3)	0.6310 (1)	0.7023 (1)	0.8556 (3)
C(4)	0.6171 (1)	0.8079 (1)	0.8952 (3)
C(5)	0.5663 (1)	0.8388 (1)	1.0502 (3)
C(6)	0.5282 (1)	0.7639 (1)	1.1659 (2)
O	0.50000	0.5949 (1)	1.2500
Cl(1)	0.69365 (3)	0.66437 (4)	0.65979 (7)
Cl(2)	0.66473 (3)	0.90157 (4)	0.74926 (9)
H(1)	0.603	0.551	0.946
H(2)	0.557	0.914	1.078

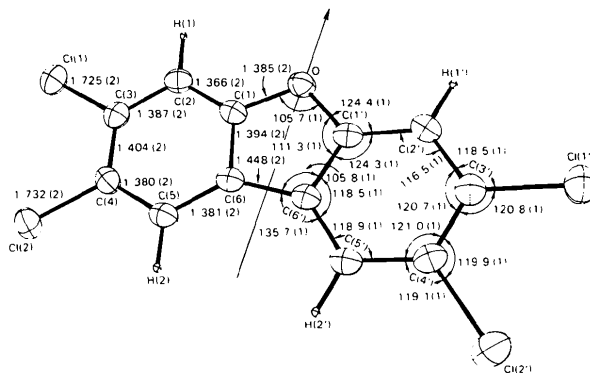


Fig. 2. Bond lengths (\AA) and angles ($^\circ$) in 2,3,7,8-tetrachlorodibenzofuran.

Discussion. Chlorinated dibenzofurans (Cl-DBF's) are reported impurities in several types of chlorinated aromatic industrial chemicals produced in the United States and abroad, including PCB's (Bowes, Mulvihill, Simoneit, Burlingame & Risebrough, 1975; Nagayama, Kuratsune & Masuda, 1976; Miyata, Nakamura & Kashimoto, 1976), pentachlorophenols (Schwetz, Keeler & Gehring, 1974; Buser, 1975) and hexachlorobenzene (Villanueva, Jennings, Burse & Kimbrough, 1974). Cl-DBF's are recognized environmental pollutants and are contaminants in foods (Department of Health, Education and Welfare, 1976; Firestone, 1973; Collins, Holmes & Wallen, 1972). Extremely high toxicity has been reported for the Cl-DBF compound whose structure is reported here (Moore, Gupta & Vos, 1976; McKinney, Chae, Gupta, Moore & Goldstein, 1976). Also, this compound is known to be a highly potent inducer of enzymes (Poland, Glover, Kende, DeCamp & Giandomenico, 1976). There is, therefore, concern that Cl-DBF's may be present as environmental or food contaminants.

TCDBF (Fig. 1a) is also suspected of being a toxic molecule because of its close structural relationship to the highly toxic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD; Fig. 1b). The principal difference between TCDBF and TCDD is that in the former the central

ring is a five-membered furan ring whereas, in the latter, the central ring is the six-membered dioxin ring. The detailed structural determination of TCDBF was undertaken to provide accurate molecular parameters which can be used in various chemical or toxicological studies on this molecule and to compare this molecule with TCDD and with the parent dibenzofuran (DBF).

TCDBF is a planar molecule with a twofold axis that passes through the O atom and bisects the C—C bond linking the two phenyl rings. Bond distances, angles, and thermal motions are shown in an *ORTEP* (Johnson, 1965) view of the molecule (Fig. 2). The

results of a least-squares plane analysis (plane calculated through all atoms except H) show that the maximum distance from the least-squares plane is 0.01 Å and the average distance is 0.006 Å. Thus, TCDBF is planar within experimental error.

A comparison of the molecular parameters of TCDBF with the parent dibenzofuran and references to two independent structural determinations of DBF are given in Table 2. The C(3)—C(4) distance in the tetrachlorodibenzofuran (Fig. 2) is lengthened due to the attachment of Cl atoms to these C atoms. Other distances and angles of this compound and DBF compare reasonably well with the possible exception of the C(6)···C(6') bond distance. This distance was believed to be abnormally long in DBF but is more normal in the tetrachloro derivative. In TCDBF there is a crystallographic twofold axis whereas in DBF there is a mirror plane. Nevertheless, both molecules are essentially planar and have the same point group $m(C_2)$. In DBF (Dideberg, Dupont & André, 1972) the maximum (0.05 Å) and the average distances (0.01 Å) of the atoms from the least-squares plane (calculated through the five-membered furan ring) are slightly greater than the corresponding distances of 0.02 and 0.007 Å in the tetrachloro derivative. The angle between the least-squares plane of the five- and six-membered rings is 1.12° (Dideberg, Dupont & André, 1972) in DBF and 0.52° in TCDBF.

The crystal structure of TCDD was solved by Boer, Van Remoortere, North & Neuman (1972). A comparison of the structural parameters shows that both TCDD and TCDBF are similar for the following reasons. (a) They are essentially planar. In TCDD there are two independent molecules in the unit cell. For both molecules the maximum and the average distances from the least-squares plane (through all atoms except H) are 0.02 and 0.01 Å respectively. (b) Both molecules have benzenoid-type rings attached to a central O-containing ring. (c) The Cl atoms are

Table 2. Comparison of bond distances (Å) and angles (°) in TCDBF and DBF

	TCDBF	DBF ^(a)	DBF ^(b)
O—C(1)	1.385 (2)	1.396 (3)	1.418 (6)
C(1)—C(2)	1.366 (2)	1.379 (3)	1.401 (8)
C(2)—C(3)	1.387 (2)	1.379 (4)	1.383 (8)
C(3)—C(4)	1.404 (2)*	1.372 (4)	1.377 (8)
C(4)—C(5)	1.380 (2)	1.383 (3)	1.386 (8)
C(5)—C(6)	1.381 (2)	1.394 (2)	1.382 (7)
C(6)—C(6')	1.448 (2)	1.475 (3)	1.480 (6)
C(6)—C(1)	1.394 (2)	1.381 (3)	1.382 (7)
C(1)'—O—C(1)	105.7 (1)	104.5 (2)	104.4 (4)
O—C(1)—C(2)	124.4 (1)	124.6 (2)	123.2 (5)
C(6)—C(1)—C(2)	124.3 (1)	123.0 (2)	123.9 (5)
O—C(1)—C(6)	111.3 (1)	112.4 (2)	112.9 (4)
C(1)—C(2)—C(3)	116.5 (1)	117.0 (2)	115.3 (5)
C(2)—C(3)—C(4)	120.7 (2)	120.7 (2)	122.1 (5)
C(5)—C(4)—C(3)	121.0 (1)	121.9 (2)	121.4 (5)
C(6)—C(5)—C(4)	118.9 (1)	118.0 (2)	118.5 (5)
C(1)—C(6)—C(5)	118.5 (1)	119.4 (2)	118.9 (4)
C(6)'—C(6)—C(5)	135.7 (1)	135.3 (2)	136.5 (4)
C(6)'—C(6)—C(1)	105.8 (1)	105.4 (2)	105.6 (4)

References: (a) Dideberg, Dupont & André (1972). (b) Banerjee (1973).

* Cl atoms attached to C(3) and C(4).

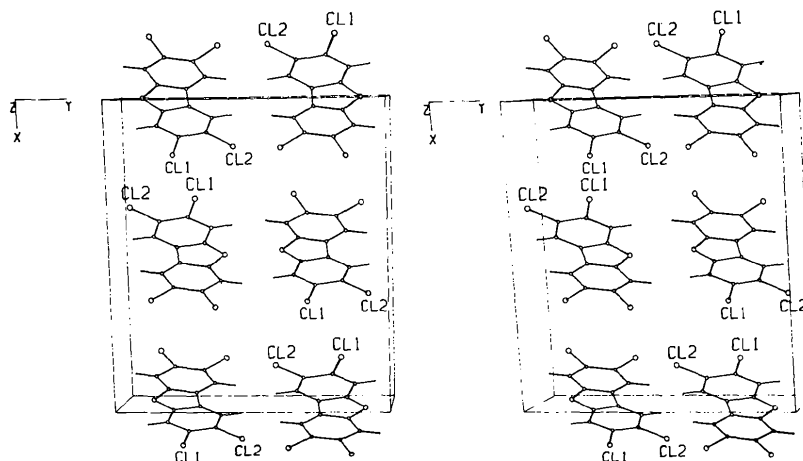


Fig. 3. Stereoscopic view of the packing in 2,3,7,8-tetrachlorodibenzofuran.

attached in the same positions in the benzenoid rings. (d) The average C—Cl bond distance (1.728 Å) is the same in both cases. TCDBF (1.745 g cm⁻³) is not as dense as TCDD (1.827 g cm⁻³). One might expect the reverse to be true, as the former has a higher percentage of Cl in the molecule; in both cases, only weak packing forces exist in the structure. The difference in density, however, is consistent with the observed nonhydrogen intermolecular contacts. For the title compound, the only contact less than 3.5 Å is between O(1) and C(2) (3.36 Å). In TCDD, there are five contacts less than 3.5 Å with the shortest (3.09 Å) between a Cl and an O atom. A packing diagram is shown in Fig. 3.

The predominant difference between the two molecules is that TCDD is far more symmetrical; it has nearly *mmm* (*D*_{2h}) symmetry. The TCDBF and TCDD molecules are thus not entirely superimposable. However, the halogenated benzenoid ring portions of the two molecules are exactly superimposable. Moreover, the geometries of the four Cl atoms in TCDD and TCDBF are similar. For example, although the Cl(2)···Cl(2)' distance is ~15% shorter in TCDBF than in TCDD, the Cl(1)···Cl(1)' distances are essentially identical in the two compounds. Considerations of structural features such as these are presumably important in coming to an understanding of the relationship between structure and biological activity in these molecules (for a discussion of this relationship, see Poland, Glover, Kende, DeCamp & Giandomenico, 1976).

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