Structure of 2-Isopropyl-5-methylphenol (Thymol)*

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Abstract

The crystal structure of the title compound, $C_{10}H_{14}O$, has been determined from Cu $K\alpha$ data by direct methods and refined to an R of 0.054. Crystals are trigonal, space group $R\bar{3}$, with unit-cell parameters (hexagonal axes): $a = b = 14.730$ (2), $c = 23.115$ (3) Å. There are 18 molecules in such a cell. The molecular configuration shows the position of the isopropyl group relative to the benzene ring while the crystal structure shows hexamers of hydrogen-bonded molecules. The hexamers, centered at the vertices of rhombohedra, are linked by van der Waals contacts.

Introduction

This work is a part of the study of isopropyl-5-methylphenols (with alternative numbering, -3-methylphenols); there are four isomers: their crystal structures are being studied in order to determine the molecular configuration and the arrangement of molecules in the crystal in relation to physical and chemical properties and also to aid the elucidation of organic solid-state reactions. 4-Isopropyl-5-methylphenol has been studied previously (Perrin, Bavoux & Thozet, 1977) and this paper concerns 2-isopropyl-5-methylphenol, the most well known isomer, called thymol. It is found naturally in large proportions in *Ptychotis ajowan* fruits (India), in *Monarda punctata* and *Mosla japonica*, and also in small quantities in thyme oil. Now it is manufactured synthetically and is an important product because it can be converted into menthol by nuclear hydrogenation. Thymol is an effective disinfectant and is used in many antiseptic preparations. It is also used as an antihelminthic.

Morphological characteristics and crystal data

Because of the ease of growing large crystals, 2-isopropyl-5-methylphenol had been studied many years

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* Alternative chemical name: 3-methyl-6-isopropylphenol. Here the numbering of the benzene ring is the reverse of that used in the title name.

before crystal structures were being determined by X-ray diffraction (Groth, 1868; Pope, 1899; Castle, 1955; Joos, 1956). These authors found that thymol crystallizes in the trigonal system and Joos determined the cell parameters with hexagonal and rhombohedral axes from Weissenberg photographs. He thought that the space group was $R\bar{3}$. However, until now the crystal structure of this compound was unknown.

We prepared large single crystals of the compound (several centimeters in all directions) by different methods (saturated solutions or melting). Stereographic projections show that two rhombohedra, {100} and {110}, and sometimes the pinacoid {111} are present. Crystals are uniaxial (+), as stated by Castle (1955); there is no optical activity; there is a very easy cleavage parallel to the faces of the rhombohedra.

X-ray studies from monocrystals determined the preliminary unit-cell dimensions and space-group extinctions. Intensity data were collected with Cu $K\alpha$ radiation on an Enraf–Nonius CAD-4 diffractometer: measurements were made with hexagonal axes and the extinctions of a rhombohedral class. The results are given in Table 1.

The numbering scheme of the different atoms of the molecule is given in Fig. 1.†

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† The atom numbering shown corresponds to the alternative chemical name (see previous footnote).

Table 1. *Crystal data*

2-Isopropyl-5-methylphenol, $C_{10}H_{14}O$

Hexagonal axes	Rhombohedral axes
$a = b = 14.730$ (2) Å	$a = b = c = 11.476$ (3) Å
$c = 23.115$ (3) Å	$\alpha = \beta = \gamma = 80.80$ (2)°
$Z = 18$	$Z = 6$

Melting point: 322.75 K
$D_x = 1.032$ Mg m^{-3}
$D_m = 1.016$ at 293 K
Space group: $R\bar{3}$ or $R3$
$F(000) = 1476$
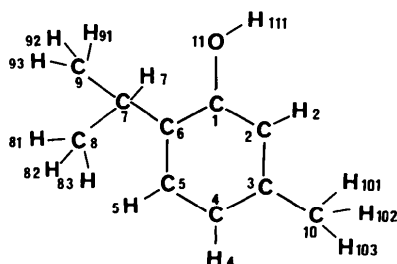Number of observed reflexions: 1312

Fig. 1. Numbering scheme of the molecule.

Structure determination and refinement

The structure factors were scaled by Wilson's (1942) method and converted to normalized structure factors $|E|$. Statistical values of the $|E|$'s show that the symmetry group is centered, *i.e.* $R3$. The structure was solved with *MULTAN* (Germain, Main & Woolfson, 1971); the lattice was considered as P and nine symmetry cards were assigned to the trigonal group. An initial E map based on 267 reflexions ($E > 1.50$) revealed the 11 non-hydrogen atoms of the molecule. The first calculation of R with all the reflexions gave 0.44. The atomic coordinates and thermal parameters, first isotropic and then anisotropic, were refined by least-squares methods (Ahmed, Hall, Pippy & Huber, 1966). The weighting scheme used was: $w^{1/2} = 1$ if $|F_o| < P_1$, $w^{1/2} = P_1/|F_o|$ if $|F_o| > P_1$, where $P_1^2/F_{max}^2 = 0.1$.

After this refinement, the conventional R value was 0.07 for 1065 reflexions.

H atoms were located on a difference map using the *SHELX* program (Sheldrick, 1976). The final R after isotropic refinement of the H atoms was 0.054 for 1183 reflexions. The final atomic positional parameters are given in Tables 2 and 3 for all atoms.*

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* Lists of structure factors and anisotropic thermal parameters and a stereoscopic view of the molecular packing have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 34965 (13 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 2. *Fractional atomic coordinates* ($\times 10^4$) *of non-hydrogen atoms with their standard deviations in parentheses, and thermal parameters* B_{eq} (Å^2)

	x	y	z	B_{eq}
C(1)	4692 (2)	3327 (2)	7574 (1)	4.31
C(2)	4855 (2)	2717 (2)	7177 (1)	4.66
C(3)	4657 (2)	2757 (3)	6595 (1)	5.16
C(4)	4303 (3)	3433 (3)	6426 (1)	6.52
C(5)	4162 (3)	4051 (3)	6824 (1)	6.19
C(6)	4349 (2)	4012 (2)	7412 (1)	4.67
C(7)	4135 (3)	4643 (3)	7851 (1)	5.49
C(8)	2974 (4)	4168 (4)	7952 (2)	9.31
C(9)	4613 (6)	5781 (4)	7691 (2)	12.8
C(10)	4831 (3)	2095 (3)	6162 (2)	6.92
O(11)	4890 (2)	3282 (2)	8159 (1)	5.37

Table 3. *Fractional atomic coordinates* ($\times 10^3$) *for hydrogen atoms with their standard deviations in parentheses, and isotropic temperature factors* B (Å^2)

	x	y	z	B
H(2)	512 (2)	222 (2)	733 (1)	4.33
H(4)	412 (2)	346 (2)	599 (1)	5.83
H(5)	387 (2)	456 (2)	668 (1)	5.43
H(7)	446 (2)	459 (2)	824 (1)	4.93
H(81)	263 (3)	337 (3)	805 (1)	8.53
H(82)	273 (3)	430 (3)	752 (1)	8.53
H(83)	283 (3)	464 (3)	826 (1)	8.53
H(91)	537 (3)	599 (3)	769 (1)	10.03
H(92)	442 (3)	621 (3)	795 (1)	10.03
H(93)	431 (3)	582 (3)	730 (1)	10.03
H(101)	434 (2)	183 (2)	584 (1)	6.33
H(102)	450 (2)	134 (2)	636 (1)	6.33
H(103)	558 (2)	235 (2)	605 (1)	6.33
H(111)	501 (2)	268 (2)	823 (1)	4.83

Results and discussion

Molecular geometry

Tables 4 and 5 list the bond distances and angles, respectively. In the benzene ring, the C—C bonds are regular with a mean value of 1.387 Å. As reported previously (Domenicano, Vaciago & Coulson, 1975; Bavoux, Perrin, Thozet, Bertholon & Perrin, 1976), the internal angles of the benzene ring differ from 120°, the values depending on the electronic properties of the substituents; the internal C(2)—C(1)—C(6) angle of 122.5° is greater than 120°, as has been found for about twenty phenols studied. In contrast, angles C(2)—C(3)—C(4) and C(1)—C(6)—C(5) are smaller than 120°. These angles carry the alkyl groups with σ-electron-releasing properties. The differences of these values from 120° are significant according to Student's test.

The equation of the benzene-ring plane and deviations of atoms from it are given in Table 6. It can be seen that the H atoms of the ring, H(2), H(4) and

Table 4. *Bond lengths* (Å) *with their standard deviations in parentheses*

C(1)—C(2)	1.387 (4)	C(2)—H(2)	1.06 (3)
C(1)—C(6)	1.385 (5)	C(4)—H(4)	1.06 (3)
C(2)—C(3)	1.383 (4)	C(5)—H(5)	1.09 (3)
C(3)—C(4)	1.391 (6)	C(7)—H(7)	1.05 (3)
C(4)—C(5)	1.380 (6)	C(8)—H(81)	1.05 (3)
C(5)—C(6)	1.393 (4)	C(8)—H(82)	1.11 (4)
C(3)—C(10)	1.507 (5)	C(8)—H(83)	1.09 (4)
C(6)—C(7)	1.512 (5)	C(9)—H(91)	1.00 (5)
C(7)—C(8)	1.508 (7)	C(9)—H(92)	1.00 (4)
C(7)—C(9)	1.505 (6)	C(9)—H(93)	1.02 (4)
C(1)—O(11)	1.392 (3)	C(10)—H(101)	0.97 (3)
		C(10)—H(102)	1.07 (3)
		C(10)—H(103)	1.00 (4)
		O(11)—H(111)	1.00 (3)

Table 5. Bond angles (°) with their standard deviations in parentheses

C(2)—C(1)—O(11)	120·2 (3)	C(9)—C(7)—H(7)	109 (2)
C(6)—C(1)—O(11)	117·3 (3)	C(6)—C(7)—H(7)	106 (2)
C(6)—C(1)—C(2)	122·5 (3)	C(7)—C(8)—H(81)	111 (2)
C(1)—C(2)—C(3)	120·4 (3)	C(7)—C(8)—H(82)	100 (2)
C(2)—C(3)—C(4)	117·8 (3)	C(7)—C(8)—H(83)	110 (2)
C(2)—C(3)—C(10)	120·7 (3)	C(7)—C(9)—H(91)	100 (2)
C(4)—C(3)—C(10)	121·5 (3)	C(7)—C(9)—H(92)	116 (2)
C(3)—C(4)—C(5)	121·2 (4)	C(7)—C(9)—H(93)	108 (2)
C(4)—C(5)—C(6)	121·6 (4)	C(3)—C(10)—H(101)	116 (2)
C(1)—C(6)—C(5)	116·4 (3)	C(3)—C(10)—H(102)	104 (2)
C(1)—C(6)—C(7)	122·0 (3)	C(3)—C(10)—H(103)	116 (2)
C(5)—C(6)—C(7)	121·5 (3)	H(81)—C(8)—H(82)	111 (3)
C(6)—C(7)—C(8)	110·8 (3)	H(81)—C(8)—H(83)	116 (3)
C(6)—C(7)—C(9)	113·2 (4)	H(82)—C(8)—H(83)	108 (3)
C(8)—C(7)—C(9)	110·2 (4)	H(91)—C(9)—H(92)	115 (3)
C(1)—C(2)—H(2)	118 (1)	H(91)—C(9)—H(93)	116 (3)
C(3)—C(2)—H(2)	122 (1)	H(92)—C(9)—H(93)	103 (3)
C(3)—C(4)—H(4)	119 (2)	H(101)—C(10)—H(102)	93 (3)
C(5)—C(4)—H(4)	119 (2)	H(101)—C(10)—H(103)	114 (3)
C(4)—C(5)—H(5)	119 (2)	H(102)—C(10)—H(103)	110 (3)
C(6)—C(5)—H(5)	119 (2)	C(1)—O(11)—H(111)	110 (2)
C(8)—C(7)—H(7)	107 (2)		

Fig. 2. Stereoscopic view of a hexamer (Johnson, 1965).

Fig. 3. Drawing showing some hydrogen-bond distances (Å) and angles (°).

Table 6. Least-squares plane and displacements (Å) of atoms

Asterisks indicate atoms not included in the calculation of the plane.

$$0·672X + 0·730Y - 0·128Z = 3·86$$

C(1)	−0·007 (3)	C(9)*	0·950 (7)
C(2)	0·007 (3)	C(10)*	0·011 (5)
C(3)	−0·000 (4)	O(11)*	−0·004 (2)
C(4)	−0·006 (4)	H(111)*	−0·17 (3)
C(5)	0·006 (4)	H(2)*	0·01 (3)
C(6)	0·001 (3)	H(4)*	−0·04 (3)
C(7)*	−0·067 (4)	H(5)*	−0·02 (3)
C(8)*	−1·452 (6)		

H(5), are in the plane, but the H atom of the OH group, H(111), is out of the plane.

The difference between the angles C(2)—C(1)—O(11) and C(6)—C(1)—O(11) has also been found in other phenols and the larger angle is on the side with the H(111) atom. H(111) is directed away from the isopropyl group which is turned so that the two atoms C(8) and C(9) are as far from the O atom as possible. The direction C(8)—C(9) is not perpendicular to the benzene-ring plane but makes an angle of about 76°. The same result was found in 4-isopropyl-5-methyl-phenol and 4-isopropylphenol (Perrin et al., 1977). The torsion angle C(1)—C(6)—C(7)—C(8) has the value $\tau = -102·6$ (4)°.

Another feature of these molecules concerns the thermal motion: isotropic B values are about 5 Å² for the ring atoms and O(11), C(7) and C(10); however, values are greater for C(8) and C(9) reaching values of
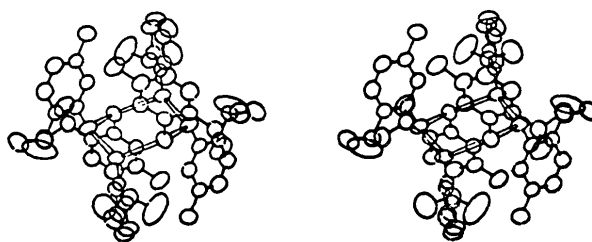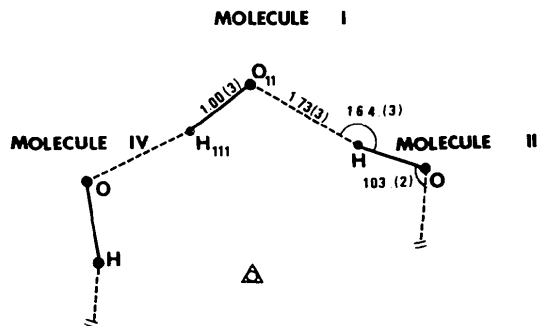
8·8 and 10·2 Å² respectively. This has been found for the other isomers and will be discussed in a future paper.

Hydrogen bonding

Molecules are linked by six hydrogen bonds related by a $\bar{3}$ axis, giving a hexamer. The six O atoms are at the vertices of a ring in the chair conformation, as can be seen in the stereoscopic view (Fig. 2). The distance between two O atoms is 2·703 (3) Å. The centers of the hexamers are repeated at the vertices of the rhombohedra. This arrangement of hexamers has also been found for 3,4-dimethylphenol (Vandenborre, Gillier-Pandraud, Antona & Becker, 1973). As was done for 3,4-dimethylphenol, we have calculated the distances to the mean plane of molecule (I) of the two O atoms O(11^{III}) and O(11^{IV}): we have found that O(11^{IV}) lies 2·38 Å and O(11^{III}) −0·81 Å out of the plane; therefore O(11^{I}) is the hydrogen donor for the O(11^{I})—H(111^{I})···O(11^{IV}) bond (Fig. 3).

The structure consists of hexamers held together by van der Waals contacts. The shortest intermolecular distances with their e.s.d.'s are listed in Table 7: bonds between molecules in the same hexamer and between molecules in two different hexamers are given. It is of note that there are many contacts between molecules (I) and (II) related by a center of symmetry.

Table 7. *Intermolecular distances* (Å) *less than* 4·0 Å *with their estimated standard deviations in parentheses*

Symmetry code

(I)	x, y, z	(IV)	$x - y + \frac{1}{3}, x - \frac{1}{3}, -z + \frac{5}{3}$
(II)	$-x + \frac{2}{3}, -y + \frac{1}{3}, -z + \frac{1}{3}$	(V)	$-x + y + 1, -x + 1, z$
(III)	$y + \frac{1}{3}, -x + y + \frac{2}{3}, -z + \frac{1}{3}$	(VI)	$y - \frac{1}{3}, -x + y + \frac{1}{3}, -z + \frac{4}{3}$
		(VII)	$-x + \frac{1}{3}, -y + \frac{2}{3}, -z + \frac{5}{3}$

Within a hexamer

C(1^I)–O(11^{III})	3·460 (4)	C(1^I)–O(11^{IV})	3·545 (4)
C(7^I)–O(11^{III})	3·713 (4)	C(2^I)–O(11^{IV})	3·554 (4)
C(6^I)–O(11^{III})	3·846 (4)	C(3^I)–C(10^V)	3·837 (6)
		C(4^I)–C(10^V)	3·844 (7)

Between hexamers

C(1^I)–C(10^{II})	3·884 (6)	C(2^I)–C(3^{II})	3·916 (5)
C(2^I)–C(10^{II})	3·853 (6)	C(2^I)–C(4^{II})	3·981 (5)
C(3^I)–C(10^{II})	3·842 (6)	C(3^I)–C(3^{II})	3·621 (5)
C(4^I)–C(10^{II})	3·857 (6)	C(3^I)–C(4^{II})	3·928 (5)
C(5^I)–C(10^{II})	3·919 (6)	C(5^I)–C(9^{VI})	3·994 (7)
C(6^I)–C(10^{II})	3·948 (5)	C(8^I)–C(9^{VII})	3·810 (8)
		C(8^I)–C(9^{v-a})	3·930 (7)

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La Structure du N,N'-Ethylène-dibenzamide

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Abstract

Crystals of N,N'-ethylenedibenzamide, $C_{16}H_{16}N_2O_2$, are orthorhombic and belong to the space group *Pbca*. The unit-cell dimensions are $a = 8·982$ (4), $b = 9·972$ (4) and $c = 15·579$ (6) Å. The structure was solved by direct methods from 542 independent intensity data measured on a Nonius CAD-4 automatic diffractometer. Full-matrix least-squares refinement of the coordinates and thermal parameters led to an R_w index of 0·030. The molecule, situated on a crystallographic centre of symmetry, consists of a central $NH–CH_2–CH_2–NH$ group between two benzoyl groups each at 69° from the plane of the central part. The conformation of this central group is *gauche-trans-gauche* and corresponds to one of the low-energy conformations computed by conformational analysis. Each molecule is connected through hydrogen bonds to four others. The hydrogen bonding is characterized by the following geometry: $N–H = 0·89$ (3), $H \cdots O = 1·98$ (3) Å and $N–H \cdots O = 167$ (3)°. The distance between the centres of the benzene rings is 10·91 Å.

Introduction

Dans une série d'articles récents nous avons montré qu'il était possible d'obtenir la géométrie et la conformation d'un polyester à partir de la structure cristalline de petites molécules organiques modèles de ce polymère. Ainsi la partie flexible du poly(éthylène téréphtalate) et du dibenzoate d'éthylène glycol, molécule modèle de ce polyester, ont même conformation. Il a aussi été établi que la même correspondance existait entre le poly(triméthylène téréphtalate) et son modèle le dibenzoate de triméthylène glycol (Pérez & Brisse, 1977; Brisse, Pérez & Marchessault, 1980; Poulin-Dandurand, Pérez, Revol & Brisse, 1979). Pour ces études les polyesters et leurs modèles avaient été choisis car seules les interactions de van der Waals maintenaient les chaînes polymériques entre elles. Afin de s'assurer que la même technique était aussi applicable en présence de ponts hydrogène, nous avons entrepris la détermination de la structure cristalline du N,N'-éthylène-dibenzamide. Cette molécule qui est isoélectronique du dibenzoate d'éthyl-