SHEFTER, E. & TRUEBLOOD, K. N. (1965). *Acta Cryst.* **18**, 1067–1077.

SHERFINSKI, J. S. & MARSH, R. E. (1973). *Acta Cryst.* **B29**, 192–198.

TOLLIN, P., WILSON, H. R. & YOUNG, D. W. (1973). *Nature New Biol.* **242**, 49–50.

TOUGARD, P. (1969). *Biochem. Biophys. Res. Commun.* **37**, 961–964.

TOUGARD, P. (1971). *C.R. Acad. Sci. Paris,* **273**, 878–879.

TOUGARD, P. (1973). *Biochem. Biophys. Acta.* Sous presse.

TOUGARD, P. & LEFEBVRE-SOUBEYRAN, O. (1973). *Acta Cryst.* A paraître.

TRUEBLOOD, K. N., HORN, P. & LUZZATI, V. (1961). *Acta Cryst.* **14**, 965–982.

VOET, D. & RICH, A. (1970). In *Prog. Nucleic Acid Res. Mol. Biol.* pp. 183–265.

YOUNG, D. W., TOLLIN, P. & WILSON, H. R. (1969). *Acta Cryst.* **B25**, 1423–1432.

The Crystal Structure of Methyl Grindelate

BY A. M. O'CONNELL*

Department of Physics, University of Western Australia, Nedlands, Australia 6009, and Crystallography Group, University of Göteborg, Medicinaregatan 9, Göteborg, Sweden

The crystal structure of methyl grindelate, $C_{21}H_{34}O_3$, has been determined from three-dimensional X-ray diffraction data. The crystals are orthorhombic, space group $P2_12_12$, with unit-cell constants $a = 39\cdot180 \pm 12$, $b = 7\cdot526 \pm 2$, $c = 6\cdot712 \pm 2$ Å. The structure was solved using the tangent formula and refined by block-diagonal least-squares techniques to $R = 0\cdot078$. The two six-membered rings are *trans* fused. Ring A has the normal chair conformation and ring B is distorted to a half chair by the olefinic double bond. A number of large deviations from the expected carbon bond lengths and valence angles are apparently due to non-bonded interactions resulting from intramolecular overcrowding.

Introduction

Grindelic acid is a plant product obtained from *Grindelia squarrosa*. Its chemical structure has been studied on the basis of degradative experiments by Panizzi, Mangoni & Belardine (1962), and Mangoni & Belardine (1963). Independently Bruun, Jackman & Stenhagen (1962) investigated grindelic and oxygrindelic acids and their esters using nuclear magnetic resonance, infrared, ultraviolet and mass spectra. Further studies of the mass spectra of these and related structures have been reported by Enzell & Ryhage (1965). On the basis of these experiments the structure of grindelic acid has been established as 9,13-epoxy-7-labden-15-oic acid. In order to confirm this structure and to obtain more precise information about the molecular geometry and stereochemistry the crystal structure analysis of methyl grindelate was undertaken. Crystal samples of the ester were kindly provided by Professor E. Stenhagen.

Experimental

Crystal data

Methyl grindelate $C_{21}H_{34}O_3$
M.W. 334
Orthorhombic

---

* Present address: C.S.I.R.O., Division of Land Resources Management, Floreat Park, Western Australia.

$a = 39\cdot182$ (12), $b = 7\cdot526$ (2),
$\qquad\qquad c = 6\cdot712$ (2) Å ($\lambda = 0\cdot71069$)
$U = 1979\cdot2$ Å³
$Z = 4$
Space group $P2_12_12$
Absent spectra: $h00$, h odd; $0k0$, k odd.
$\mu = 0\cdot79$ cm⁻¹ for Mo $K\alpha$ radiation.

The cell constants and reflexion data were measured on a Picker FACS1 diffractometer using a spherical crystal 0·6 mm in diameter and Zr-filtered Mo $K\alpha$ radiation. Intensities were recorded by the $\omega/2\theta$ scan technique with a scan speed of 1° per min and a scan range of 1° for reflexions with 2θ less than 10°. For reflexions with 2θ greater than 10° a minimum scan of 1·3° was used. This range was continuously incremented to account for the increased $\alpha_1-\alpha_2$ dispersion at higher Bragg angles. Stationary background counts of 20 sec were made at the start and finish of each scan range.

A total of 2662 reflexions having $2\theta \le 55°$ were recorded. All these reflexions were included in the subsequent least-squares refinement. When calculating Fourier syntheses or R values based on F_o, negative $|F_o|^2$ values were set to zero. The reflexion data were corrected for Lorentz and polarization factors but not for extinction or absorption.

Solution

The structure was solved by means of the tangent formula (Karle & Karle, 1966) using the program system of Hall (1968). Four phases were chosen to define the origin and enantiomorph (Table 1) according to Karle & Hauptman (1956). This set was extended and refined using the tangent formula. Initially only terms with normalized structure factors $|E| \geq 1.8$ were included in the calculations. After a number of iterations this limit was gradually reduced to 1·5, the phases of 216 reflexions being determined in this way.

Table 1. Initial phase assignments

h	k	l	ϕ	$|E|$
34	0	5	0	3·24
2	1	0	0	2·60
39	1	0	0	2·06
31	0	6	1½	2·03

Several generations using different sets of starting phases were carried out before a self consistent set of final phases was obtained. The criteria of a uniform distribution of calculated $|E|$ values and no large phase-angle oscillations were used to assess the reliability of the generated phases. The set of phases calculated from those listed in Table 1 had only three $|E \text{ calc}|$ values less than 0·5 and there were no large phase oscillations in the final tangent cycle.

A Fourier E map based on this set showed 16 of the atomic peaks. The remaining atoms were fixed from a difference synthesis.

The structure was refined using block-diagonal least-squares techniques to minimize the quantity $\sum w(F_o^2 - F_c^2)$. Weights were initially based on counting statistics according to Evans (1961), however somewhat better convergence was obtained in the final stages using the function

$$w = \{(F_o^2 + 6) [49 + (F_o^2 - 7)^2]\}^{-1}.$$

The carbon and oxygen atoms were refined with anisotropic thermal parameters. At $R = 0.10$ a difference synthesis revealed the positions of all hydrogen atoms. These were included in the refinement with isotropic thermal parameters. The final R index including all reflexions was 0·078. The atomic coordinates and thermal parameters are listed in Tables 2 and 3.

For hydrogen the scattering curve of Stewart, Davidson & Simpson (1965) was used and for carbon and oxygen the values listed in International Tables for X-ray Crystallography (1962) were assumed.

Discussion

The molecular stereochemistry and atom numbering are shown in Fig. 1. The two six-membered rings are *trans* fused at C(5)–C(10). Ring A has the normal chair conformation and ring B is distorted to a half chair by the olefinic double bond C(7)–C(8).

Table 2. Atomic coordinates and hydrogen atom isotropic thermal parameters

The positional e.s.d.'s for C and O are multiplied by 10^5 and for H by 10^4. Hydrogen B value e.s.d.'s are multiplied by 10.

	x/a	y/b	z/c	B
C(1)	0·36674 (7)	0·37614 (48)	0·47016 (49)	
C(2)	0·33962 (9)	0·49658 (54)	0·56347 (58)	
C(3)	0·31647 (7)	0·57326 (43)	0·40452 (65)	
C(4)	0·29799 (7)	0·43257 (37)	0·28434 (51)	
C(5)	0·32437 (6)	0·29454 (33)	0·20334 (39)	
C(6)	0·30764 (6)	0·14302 (42)	0·09107 (45)	
C(7)	0·33249 (7)	0·00513 (39)	0·02408 (39)	
C(8)	0·36452 (6)	−0·00625 (36)	0·07792 (39)	
C(9)	0·38019 (6)	0·13050 (32)	0·21993 (37)	
C(10)	0·35172 (6)	0·22129 (35)	0·34993 (36)	
C(11)	0·40981 (7)	0·05143 (39)	0·34539 (42)	
C(12)	0·44182 (6)	0·08910 (41)	0·22462 (45)	
C(13)	0·43377 (5)	0·26026 (36)	0·11279 (37)	
C(14)	0·44593 (6)	0·26272 (44)	−0·10180 (41)	
C(15)	0·48378 (6)	0·24893 (39)	−0·13793 (42)	
C(16)	0·52526 (7)	0·24133 (51)	−0·39478 (52)	
C(17)	0·28079 (8)	0·52313 (51)	0·10588 (71)	
C(18)	0·26935 (7)	0·35001 (46)	0·41272 (67)	
C(19)	0·38621 (8)	−0·15178 (45)	−0·00925 (58)	
C(20)	0·33749 (8)	0·07920 (46)	0·49419 (44)	
C(21)	0·44634 (7)	0·42441 (41)	0·22545 (50)	
O(1)	0·39684 (3)	0·26483 (22)	0·09810 (24)	
O(2)	0·49033 (4)	0·25492 (34)	−0·33290 (28)	
O(3)	0·50558 (4)	0·23387 (41)	−0·01670 (29)	
H(11)	0·3797 (5)	0·3348 (32)	0·5773 (38)	5·6 (6)
H(12)	0·3785 (6)	0·4456 (34)	0·3762 (41)	6·4 (6)
H(21)	0·3268 (6)	0·4305 (37)	0·6581 (45)	7·5 (7)
H(22)	0·3518 (7)	0·5881 (45)	0·6450 (50)	9·4 (9)
H(31)	0·2984 (8)	0·6498 (47)	0·4661 (47)	9·8 (9)
H(32)	0·3288 (6)	0·6421 (41)	0·3054 (44)	7·9 (8)
H(51)	0·3370 (4)	0·3654 (27)	0·1151 (32)	3·3 (4)
H(61)	0·2921 (6)	0·1825 (38)	−0·0225 (39)	7·1 (7)
H(62)	0·2904 (6)	0·0789 (34)	0·1859 (38)	6·3 (6)
H(71)	0·3246 (5)	−0·0757 (31)	−0·0656 (35)	5·2 (6)
H(111)	0·4051 (6)	−0·0812 (35)	0·3715 (41)	6·8 (7)
H(112)	0·4086 (5)	0·1124 (34)	0·4720 (37)	6·0 (6)
H(121)	0·4591 (6)	0·0965 (37)	0·3058 (40)	6·5 (7)
H(122)	0·4440 (6)	−0·0064 (35)	0·1354 (37)	5·8 (6)
H(141)	0·4387 (5)	0·3731 (32)	−0·1616 (35)	5·2 (6)
H(142)	0·4363 (5)	0·1669 (28)	−0·1821 (32)	4·4 (5)
H(161)	0·5252 (8)	0·2477 (63)	−0·5521 (57)	13·6 (12)
H(162)	0·5323 (7)	0·1264 (50)	−0·3614 (56)	10·8 (10)
H(163)	0·5380 (7)	0·3346 (45)	−0·3462 (50)	9·4 (7)
H(171)	0·2688 (7)	0·6127 (47)	0·1510 (55)	10·2 (9)
H(172)	0·2949 (6)	0·5714 (37)	0·0083 (38)	6·6 (7)
H(173)	0·2636 (7)	0·4349 (47)	0·0404 (52)	11·1 (10)
H(181)	0·2768 (7)	0·2907 (48)	0·5187 (51)	10·8 (10)
H(182)	0·2532 (7)	0·4425 (39)	0·4550 (44)	7·4 (8)
H(183)	0·2555 (7)	0·2441 (47)	0·3352 (54)	10·3 (9)
H(191)	0·3702 (7)	−0·2318 (52)	−0·0813 (56)	11·4 (10)
H(192)	0·4028 (7)	−0·1144 (47)	−0·0764 (53)	10·7 (10)
H(193)	0·3923 (7)	−0·2268 (48)	0·1133 (57)	11·5 (10)
H(201)	0·3308 (7)	−0·0136 (48)	0·4265 (52)	10·5 (10)
H(202)	0·3202 (6)	0·1276 (41)	0·5903 (47)	8·5 (8)
H(203)	0·3557 (8)	0·0489 (41)	0·5745 (58)	11·7 (11)
H(211)	0·4368 (7)	0·4196 (40)	0·3711 (47)	8·4 (8)
H(212)	0·4377 (6)	0·5307 (39)	0·1550 (43)	7·7 (8)
H(213)	0·4720 (5)	0·4188 (33)	0·2196 (35)	5·6 (6)

Bond lengths are shown in Fig. 2 and valence angles in Table 4. Some non-bonded intramolecular distances are listed in Table 5 and least-squares planes through various parts of the molecule in Table 6. A number of the bond distances and valence angles differ significantly (by up to 0·03 Å and 9° respectively) from the

Table 3. *Thermal parameters (with e.s.d.'s × 10⁵) in the form* $exp\,[-(b_{11}h^2 + b_{22}k^2 + b_{33}l^2 + 2b_{12}hk + 2b_{13}hl + 2b_{23}kl)]$

	b_{11}	b_{22}	b_{33}	b_{12}	b_{13}	b_{23}
C(1)	0·00104 (2)	0·03248 (80)	0·03248 (91)	−0·00001 (12)	−0·00045 (13)	−0·01306 (81)
C(2)	0·00138 (3)	0·03766 (97)	0·04667 (122)	−0·00116 (15)	0·00161 (17)	−0·02362 (100)
C(3)	0·00104 (3)	0·02263 (64)	0·06015 (136)	−0·00018 (11)	0·00255 (17)	−0·00941 (91)
C(4)	0·00073 (2)	0·02122 (57)	0·04794 (109)	−0·00002 (9)	0·00163 (13)	0·00168 (77)
C(5)	0·00062 (2)	0·01745 (49)	0·02662 (67)	−0·00036 (8)	0·00052 (9)	0·00300 (53)
C(6)	0·00072 (2)	0·02859 (69)	0·03190 (81)	−0·00047 (10)	−0·00065 (12)	−0·00088 (74)
C(7)	0·00099 (2)	0·02180 (57)	0·02360 (65)	−0·00134 (10)	−0·00018 (11)	−0·00304 (65)
C(8)	0·00090 (2)	0·01710 (46)	0·02228 (61)	−0·00021 (9)	−0·00013 (10)	−0·00017 (59)
C(9)	0·00070 (2)	0·01644 (45)	0·02054 (59)	−0·00022 (8)	−0·00035 (9)	0·00174 (53)
C(10)	0·00080 (2)	0·01845 (49)	0·01981 (46)	0·00006 (8)	−0·00013 (9)	−0·00139 (55)
C(11)	0·00095 (2)	0·02341 (61)	0·02497 (68)	0·00037 (10)	−0·00074 (11)	0·00500 (61)
C(12)	0·00071 (2)	0·02743 (67)	0·03149 (80)	0·00086 (10)	−0·00111 (11)	0·00257 (71)
C(13)	0·00054 (1)	0·02035 (50)	0·02587 (61)	−0·00004 (8)	−0·00070 (9)	0·00036 (66)
C(14)	0·00066 (2)	0·02821 (67)	0·02702 (68)	0·00033 (10)	−0·00053 (9)	0·00287 (79)
C(15)	0·00073 (2)	0·02179 (55)	0·03091 (70)	0·00010 (10)	−0·000004 (9)	0·00028 (73)
C(16)	0·00104 (2)	0·03117 (78)	0·04491 (103)	0·00007 (13)	0·00224 (14)	−0·00061 (108)
C(17)	0·00099 (3)	0·03471 (93)	0·06872 (153)	0·00188 (13)	0·00056 (20)	0·01283 (124)
C(18)	0·00087 (2)	0·02918 (78)	0·06794 (158)	0·00034 (11)	0·00374 (17)	−0·00040 (108)
C(19)	0·00125 (3)	0·02493 (70)	0·04896 (118)	0·00062 (12)	−0·00012 (16)	−0·01461 (87)
C(20)	0·00131 (3)	0·03089 (79)	0·02229 (68)	0·00024 (13)	0·00110 (12)	0·00519 (71)
C(21)	0·00074 (2)	0·02620 (67)	0·03753 (92)	−0·00065 (10)	−0·00055 (12)	−0·00536 (77)
O(1)	0·00054 (1)	0·01851 (32)	0·02530 (40)	0·00007 (5)	−0·00060 (5)	0·00391 (40)
O(2)	0·00082 (1)	0·03982 (56)	0·03112 (49)	0·00076 (8)	0·00082 (7)	0·00180 (59)
O(3)	0·00070 (1)	0·05693 (80)	0·03751 (55)	0·00102 (10)	−0·00058 (8)	0·00208 (77)

Table 4. *Bond angles and (in parentheses) their e.s.d.'s*

C(2)—C(1)—C(10)	113·5	(0·3)°
C(1)—C(2)—C(3)	110·7	(0·3)
C(2)—C(3)—C(4)	113·3	(0·3)
C(3)—C(4)—C(5)	109·5	(0·2)
C(3)—C(4)—C(17)	108·4	(0·3)
C(3)—C(4)—C(18)	109·3	(0·2)
C(5)—C(4)—C(17)	108·3	(0·2)
C(5)—C(4)—C(18)	114·0	(0·2)
C(17)—C(4)—C(18)	107·2	(0·3)
C(4)—C(5)—C(6)	112·8	(0·2)
C(4)—C(5)—C(10)	118·1	(0·2)
C(6)—C(5)—C(10)	110·2	(0·2)
C(5)—C(6)—C(7)	113·0	(0·2)
C(6)—C(7)—C(8)	126·0	(0·3)
C(7)—C(8)—C(9)	120·8	(0·2)
C(7)—C(8)—C(19)	118·8	(0·3)
C(9)—C(8)—C(19)	120·3	(0·2)
C(8)—C(9)—C(10)	110·7	(0·2)
C(8)—C(9)—C(11)	112·3	(0·2)
C(8)—C(9)—O(1)	107·3	(0·2)
C(10)—C(9)—C(11)	113·3	(0·2)
C(10)—C(9)—O(1)	109·2	(0·2)
C(11)—C(9)—O(1)	103·7	(0·2)
C(1)—C(10)—C(5)	109·1	(0·2)
C(1)—C(10)—C(9)	105·5	(0·2)
C(1)—C(10)—C(20)	109·5	(0·2)
C(5)—C(10)—C(9)	107·0	(0·2)
C(5)—C(10)—C(20)	113·1	(0·2)
C(9)—C(10)—C(20)	107·6	(0·2)
C(9)—C(11)—C(12)	104·8	(0·2)
C(11)—C(12)—C(13)	104·5	(0·2)
C(12)—C(13)—C(14)	114·4	(0·2)
C(12)—C(13)—C(21)	111·9	(0·2)
C(12)—C(13)—O(1)	105·1	(0·2)
C(14)—C(13)—C(21)	111·0	(0·2)
C(14)—C(13)—O(1)	104·4	(0·2)
C(21)—C(13)—O(1)	109·6	(0·2)
C(13)—C(14)—C(15)	117·5	(0·2)
C(14)—C(15)—O(2)	110·2	(0·2)
C(14)—C(15)—O(3)	127·3	(0·3)
O(2)—C(15)—O(3)	122·6	(0·3)
C(9)—O(1)—C(13)	113·1	(0·2)
C(15)—O(2)—C(16)	117·7	(0·2)

standard values involving sp^2 and sp^3 carbon atoms. These differences appear to result largely from repulsive forces arising from short non-bonded interactions due to the intramolecular overcrowding.

Table 5. *Some intramolecular non-bonded distances*

C(2)--C(18)	3·134 Å
C(2)--C(20)	3·176
C(3)--C(17)	2·473
C(4)--C(10)	2·674
C(4)--C(20)	3·384
C(10)-C(18)	3·396
C(13)-C(15)	2·584
C(14)-O(1)	2·345
C(14)-O(2)	2·332
C(14)-O(3)	2·416
C(15)-C(16)	2·370
C(18)-C(20)	3·403

The distortion of the valence angles in ring A is due to repulsive interaction between the diaxial methyl groups C(18) and C(20). In a regular cyclohexane ring the non-bonded distances C(4)–C(10) and C(18)–C(20) would be 2·52 Å; these distances are increased to 2·67 and 3·40 Å, respectively. The five similar distances within ring A have a mean value of 2·53 ± 0·03 Å. The repulsion between the two methyl groups causes an increase in the angles C(4)–C(5)–C(10) (=118·1°), C(5)–C(4)–C(18) (=114·0°) and C(5)–C(10)–C(20) (=113·1°). In addition the ring is also distorted by the repulsive forces between both methyl groups and the axial hydrogen at C(2). The strain is relieved by a flattening of the ring at C(2) so that the angles at C(1) and C(3) are increased by about 4° from their expected tetrahedral values. Atoms C(1)–C(3)–C(4)–C(10) are planar within experimental error. C(2) and C(5) are 0·68 and 0·54 Å above and below this plane, respec-

tively, compared with the expected value of ±0·73 Å in a regular cyclohexane ring.

Ring *B* has a distorted half-chair conformation. C(6), C(7), C(8), C(9) and C(19) at the double bond are only approximately planar, there being significant out-of-plane deviations for both C(8) and C(19). C(5) and C(10) deviate from this plane by −0·26 and 0·55 Å, respectively, as compared with the expected value of ±0·43 Å (Corey & Sneen, 1955). According to Bucourt & Hainaut (1965) the angles at the trigonal carbon atoms of a 4,5 disubstituted cyclohexene should be 124·0° and the other ring angles should be
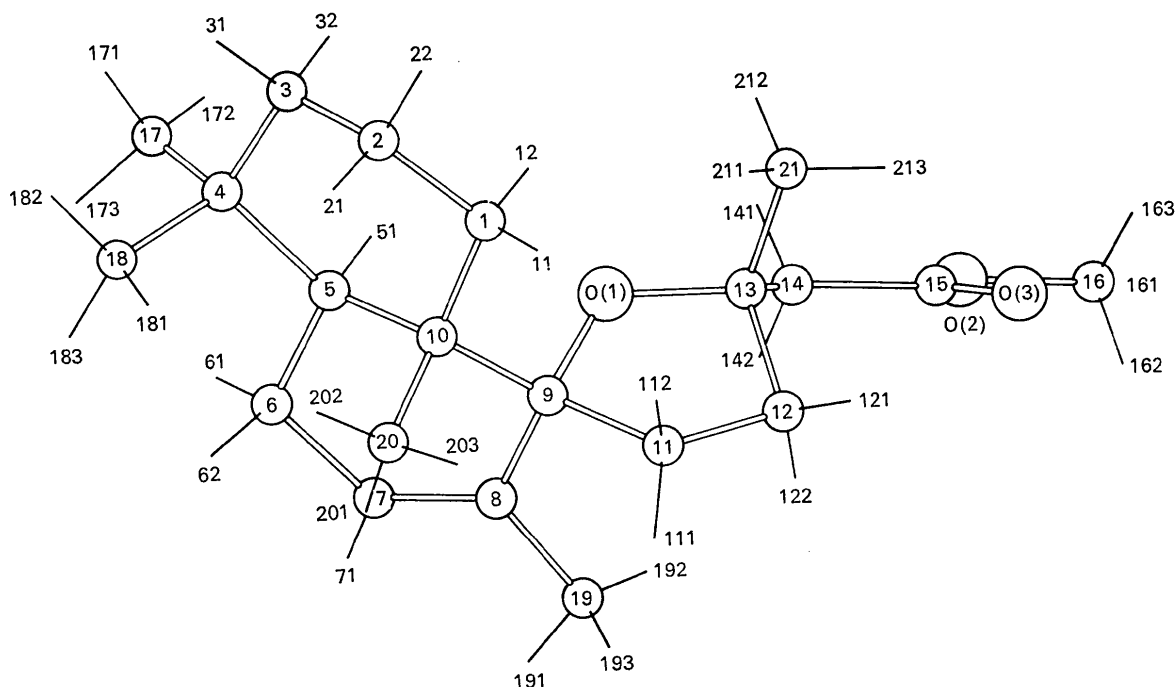
Fig. 1. Molecular stereochemistry and atom numbering.
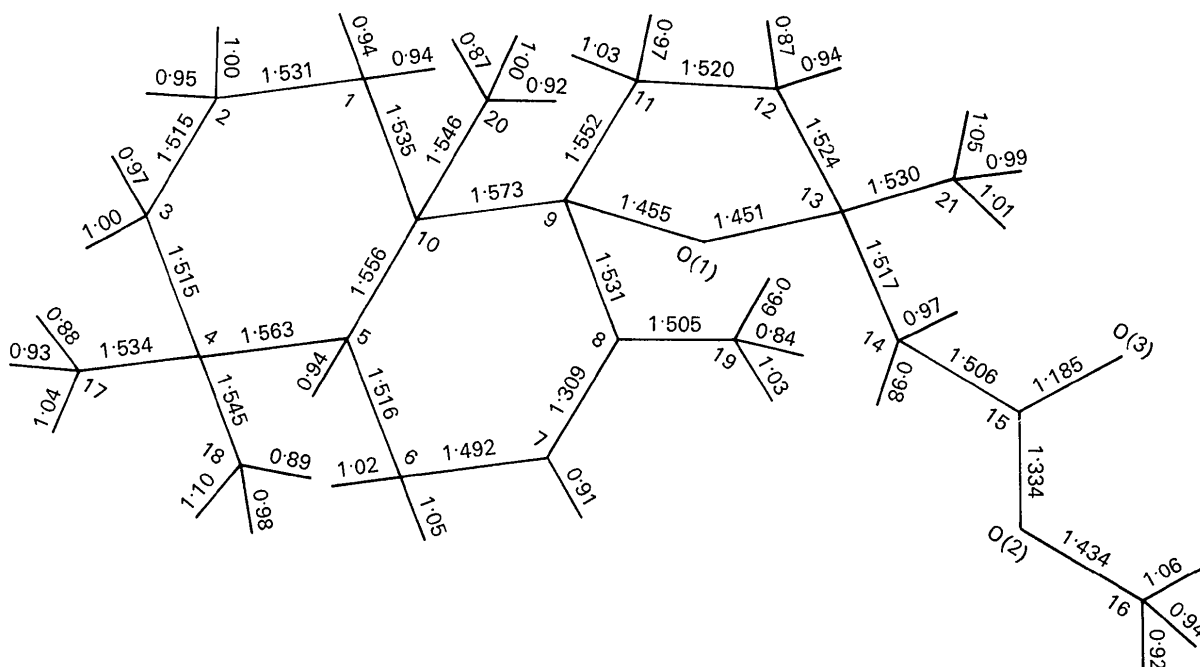
Fig. 2. Intramolecular bond distances. The mean e.s.d.'s in the C–O, C–C and C–H bonds are 0·003, 0·004 and 0·03 Å respectively.

110·5°. The mean values within ring *B* lie close to these values although the individual angles differ by up to 3·5° from them.

The ester group is planar and is approximately parallel to the *xy* plane. Atoms O(1) and C(13) also lie close to this plane. A number of the angles within this group deviate significantly from their expected values, notably C(13)–C(14)–C(15) (= 117·5°) and C(15)–O(2)–C(16) (= 117·7°). These distortions probably also results from non-bonded repulsions.

Three of the sp^3-sp^3 carbon bonds are significantly longer than the normal value of 1·537 ± 6 Å (Sutton, 1965). The longest of these, C(9)–C(10) = 1·573 Å, is between two tetra-substituted carbon atoms while the remaining two are between tetra- and tri-substituted carbon atoms [C(4)–C(5) = 1·563 Å; C(5)–C(10) = 1·556 Å]. Lengthening of bonds due to steric effects has been noted in a number of overcrowded molecules, *e.g.* methyl melaleucate iodoacetate (Hall & Maslen, 1965), iso-eremolactone (Oh & Maslen, 1968). Similar effects probably also account for the long C(8)–C(9) bond (1·531 Å) compared with the expected value of 1·501 Å for an sp^3-sp^2 carbon bond (Lide, 1962). There is no significant difference between the two C–O bonds involving the ether oxygen. The distance C(15) = O(3) (= 1·185 Å) is shorter than the accepted value, however this may be due to thermal effects since O(3) has a large component of vibration normal to the ester group plane (r.m.s. amplitude = 0·41 Å).

The mean C–H bond distance (0·97 Å) and the mean valence angle involving hydrogen (109·3°) are in agreement with the values usually obtained by X-ray diffraction techniques. The hydrogen atom thermal parameters are also physically reasonable. The isotropic thermal coefficients of the methyl group hydrogens are generally higher (mean value 9·8 Å^2) than those at the methylene carbon atoms (mean value 6·5 Å^2) which is consistant with the expected torsional vibration of the methyl groups.

The molecules pack head-to-head tail-to-tail with their longest dimension parallel to **a** (Fig. 3). The gem-dimethyl groups are involved in weak van der Waals interactions across the plane $\frac{1}{4}, y, z$; $\frac{3}{4}, y, z$. The only intermolecular contact less than 4 Å across these planes is C(6)–C(17) = 3·82 Å (Table 7). The methyl ester groups all lie close to $x = 0$, 0·5 etc. Of the eleven intermolecular contacts less than 3·8 Å, ten are associated with this part of the molecule (Table 7). The other short contact [C(7)–C(20) = 3·61 Å] involves one of the atoms of the olefinic bond with the axial methyl group at C(10) and is almost parallel to the *c* axis.

Table 7. *Intermolecular contacts less than* 3·8 Å

C(7)--C(20)	1 [0, 0, − 1]	3·605 Å
C(11)–C(16)	11 [1, 0, 1]	3·791
C(12)–O(2)	1 [0, 0, 1]	3·740
C(12)–O(3)	11 [1, 0, 0]	3·575
C(12)–C(16)	11 [1, 0, 1]	3·791
C(15)–O(3)	11 [1, 0, 0]	3·747
C(16)–C(21)	11 [1, 1, − 1]	3·750
C(21)–O(2)	1 [0, 0, 1]	3·659
C(21)–O(3)	11 [1, 1, 0]	3·578
O(2)--O(2)	11 [1, 1, 0]	3·766
O(3)--O(3)	11 [1, 0, 0]	3·547

I and II refer to the equivalent positions *x*, *y*, *z* and *x̄*, *ȳ*, *z* and the numbers in the square brackets indicate unit translations in the three axial directions.
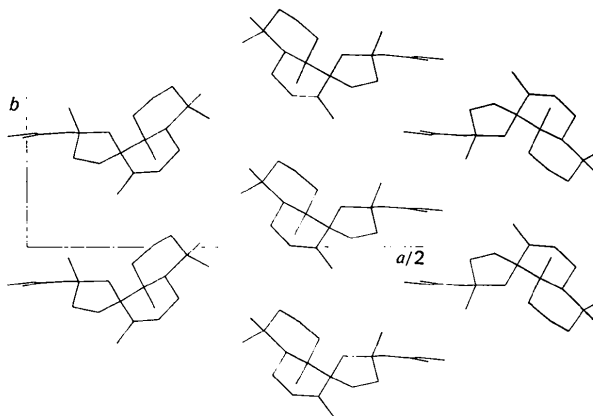

Fig. 3. Intermolecular packing viewed down the *c* axis.

Table 6. *Displacements from least-squares planes* (Å)

	Plane 1		Plane 2		Plane 3		Plane 4
	Ring *A*		Ring *B*		Ester group		Ether ring
C(1) 0·006		C(5)* −0·256		C(13)* 0·009		C(9) −0·098
C(2)* 0·680		C(6) −0·007		C(14) −0·004		C(11) 0·200
C(3) −0·006		C(7) 0·005		C(15) 0·003		C(13) −0·170
C(4) 0·006		C(8) 0·017		C(16) −0·004		C(13) 0·093
C(5)* −0·542		C(9) −0·003		O(1)* −0·081		O(1) −0·024
C(10) −0·006		C(10)* 0·554		O(2) 0·005		
		C(19) −0·010		O(3) 0·000		

Plane 1: $-0.439X - 0.343Y + 0.830Z + 4.663 = 0$
Plane 2: $-0.252X - 0.583Y + 0.772Z + 3.191 = 0$
Plane 3: $0.082X + 0.995Y + 0.049Z - 3.373 = 0$
Plane 4: $0.045X + 0.655Y + 0.755Z - 2.523 = 0$

* Atoms not included in the calculation of the plane.

References

BRUUN, T., JACKMAN, L. M. & STENHAGEN, E. (1962). *Acta Chem. Scand.* **16**, 1675–1681.

BUCOURT, R. & HAINAUT, D. (1965). *Bull. Soc. Chim. Fr.* pp. 1366–1378.

COREY, E. J. & SNEEN, R. A. (1955). *J. Amer. Chem. Soc.* **77**, 2505–2509.

ENZELL, C. & RYHAGE, R. (1965). *Ark. Kem.* **23**, 367–399.

EVANS, H. T. (1961). *Acta Cryst.* **14**, 689.

HALL, S. R. (1968). *Direct Phasing Methods.* Univ. of Western Australia, Computer Program UWAC-17.

HALL, S. R. & MASLEN, E. N. (1965). *Acta Cryst.* **18**, 265–279.

International Tables for X-ray Crystallography (1962). Vol. III, p. 202. Birmingham: Kynoch Press.

KARLE, J. & HAUPTMAN, H. (1956). *Acta Cryst.* **9**, 635–651.

KARLE, J. & KARLE, I. L. (1966). *Acta Cryst.* **21**, 849–868.

LIDE, D. R. (1962). *Tetrahedron,* **17**, 125–134.

MANGONI, L. & BELARDINE, M. (1963). *Gazz. Chim. Ital.* **93**, 455–464.

OH, Y. L. & MASLEN, E. N. (1968). *Acta Cryst.* **B24**, 883–897.

PANIZZI, L., MANGONI, L. & BELARDINE, M. (1962). *Gazz. Chim. Ital.* **92**, 522–538.

STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* **42**, 3175–3187.

SUTTON, L. E. (1965). *Tables of Interatomic Distances and Configuration in Molecules and Ions.* Special Publication No. 18. London: The Chemical Society.

The Crystal Structure of Dextrorotatory 2'-O-Tetrahydropyranyluridine

BY P. H. STOTHART AND I. D. BROWN

Department of Physics, McMaster University, Hamilton, Ontario, Canada L8S 4M1

AND T. NEILSON

Department of Biochemistry, McMaster University, Hamilton, Ontario, Canada L8S 4K1

The dextrorotatory diastereoisomer of 2'-O-tetrahydropyranyluridine ($C_{14}H_{20}N_2O_7$) crystallizes in the orthorhombic space group $P2_12_12_1$ (D_2^4) with $a = 6.716$ (2), $b = 10.124$ (4), $c = 22.720$ (12) Å, and $Z = 4$. The structure has been determined by direct methods and refined to $R = 0.039$ with 1172 reflexions measured on a single-crystal X-ray diffractometer. The absolute configuration about the acetal carbon centre [C(2")] is R. Conformation of the ribose ring is C(2')-*endo*. Bond lengths and angles (standard errors 0.004 Å and 0.3° respectively) are similar to those in related compounds. An explanation of the difference in polarity between the two diastereoisomers is given in terms of intramolecular hydrogen bonding in organic solvents.

Introduction

The formation of a chiral acetal carbon atom [C(2")] during the condensation of dihydropyran with a 2'-hydroxyl group of a nucleoside results in the existence of diastereoisomeric pairs for each 2'-O-tetrahydropyranylnucleoside (*e.g.*, (I) and (II) in Fig. 1) (Griffin, Jarman & Reese, 1968). The physical properties of the diastereoisomers are quite different, allowing convenient separation by fractional crystallization. The more dextrorotatory isomers of (I) and (II) are markedly less polar, possess lower melting points, and are more mobile in chromatographic systems with organic solvents.

An X-ray crystal structure determination of the more laevorotatory isomer of 2'-O-tetrahydropyranyladenosine [ThPA(−)] (II in Fig. 1) (Kennard, Motherwell, Coppola, Griffin, Reese & Larson, 1971) has shown that the acetal carbon atom C(2") possesses the S absolute configuration in agreement with conclusions reached from studies on the tetrahydropyranyl ethers of a series of six related steroids (Klyne, Mose, Scopes, Holder & Whalley, 1971). In this paper we show that in the more dextrorotatory isomer of 2'-O-tetrahydropyranyluridine [ThPU(+)] (I in Fig. 1) the C(2") carbon atom has the R absolute configuration.

Experimental method

Dextrorotatory 2'-O-tetrahydropyranyluridine [ThPU(+)] was prepared by the method of Griffin *et al.* (1968). Crystals suitable for X-ray work were grown from a methylene chloride solution. The space group was assigned unambiguously as $P2_12_12_1$ on the basis of the Laue symmetry and the systematic absences (for $h00$: $h = 2n + 1$; for $0k0$: $k = 2n + 1$; for $00l$: $l = 2n + 1$). The intensities of 2007 reflexions in the hkl and $hk\bar{l}$ quadrants were measured on a Syntex diffractometer from a crystal $0.51 \times 0.39 \times 0.18$ mm with crystal monochromated Mo $K\alpha$ radiation. They were averaged