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X-RAY CRYSTALLOGRAPHIC DETERMINATION OF PREROTUNDIFURAN

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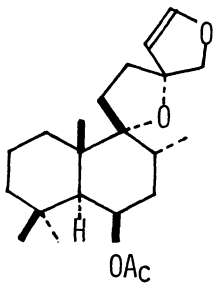
Crystal and molecular structure of a new diterpenoid, prerotundifuran, the constituent of Vitex rotundifolia, has been determined by the X-ray method.

In the preceding paper,[1] the isolation and characterization of new diterpenoids, rotundifuran and prerotundifuran, were reported. In this communication, we present the determination of the stereochemistry of prerotundifuran (I).

The crystals,[2] $C_{22}H_{34}O_4$, are orthorhombic, space group $P2_12_12_1$; m.p. 204°-205°; a=12.12 (1)Å, b=15.36 (1)Å, c=10.85 (1)Å; Dx=1.19 g·cm^{-3} (Z=4). Weissenberg intensity data were collected by means of Cu Kα radiation for 12 layers on the a axis and two layers on the c axis. The independent 2363 reflections were observed. No corrections were made for absorption and extinction.



(I)

The crystal structure of prerotundifuran was solved by the multisolution-method described by Woolfson and Germain.[3] The starting set of phases is listed in Table 1. In order to apply the tangent formula,[4] numerical phases 45° to 315° in steps of 90° were assigned to the symbols B and C, and 0° and 180° to the symbol A. Tangent refinement was carried out for each of the 32 possible phase combinations and the number of reflections included was gradually increased from 100 with E > 1.87 to 400 with E > 1.33. The final value of R (Karle)[5] ranged from 0.23 to 0.32 and that of Z[6] from 6534 to 9745. An E-map was calculated using 398 reflections with the phases in the most consistent set (R=0.23 and Z=9745). The initial and refined phases in this set are shown in parentheses in Table 1. Interestingly, the initial set of phases (0° for 10 1 0, 45° for 6 8 5, 315° for 3 3 9) could not be successfully refined by the tangent formula, although these values are very close to refined phases.

Table 1. The starting set of phases.

h	k	l	E	φ
0	9	8	3.38	90°
0	12	3	2.50	0° origin
5	13	0	1.93	90°
6	0	3	2.17	90° enantiomorph
12	0	0	2.90	180° from Σ_1
10	1	0	2.92	A (0°→ 0°)
6	8	5	2.82	B (135°→ 78°)
3	3	9	2.81	C (225°→ 322°)

The failure in phase refinements with this starting set was due to the large phase errors in the initial stage of the phase determination and propagation of these errors to other phases in the later stage. The positions of 24 non-hydrogen atoms were easily located and further confirmed by a least-squares refinement. The two remaining carbon atoms (C15 and C22) were found by a difference Fourier synthesis. When anisotropic thermal factors were applied to all of the non-hydrogen atoms, the conventional R factor was reduced to 0.10.[7] The final coordinates of the carbon and oxygen atoms are listed in Table 2. Bond distances and angles in a molecule are shown in Table 3. The estimated errors in bond distances and angles are 0.009 Å and 0.6°,respectively. The molecular structure of prerotundifuran was confirmed unambiguously and is illustrated in Fig. 1. The anisotropy of the thermal ellipsoid of O4 atom may be due to large thermal motion normal to the plane defined by C21, C22 and O3.

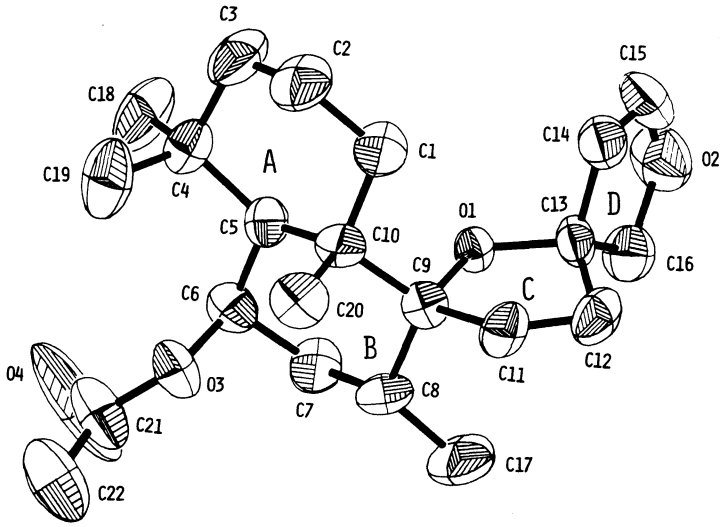


Figure 1. The molecular structure of prerotundifuran.

Ring A has a slightly distorted chair conformation with deviations from the least-squares plane ranging from 0.29 Å (C2) to 0.19 Å (C5) and with torsional angles ranging from 49° to 64°. Ring B is also in a slightly distorted chair conformation with the ring torsional angles varying between 53° and 61°. Deviations from the least-squares plane range from 0.27 Å (C8 and C9) to 0.21 Å (C5 and C6). Ring C has an 'envelope' conformation with C12 displaced by 0.45 Å out of the plane which contains the other atoms within 0.02 Å. Ring D is approximately planar within 0.08 Å, but is also in an 'envelope' conformation; C13, C14, C15 and O2 are coplanar within 0.02 Å and C16 is by 0.22 Å out of the plane.

CH_3(19) on C4, CH_3(20) on C10 and O3 on C6 are all axial. For an idealized model of the molecule with the tetrahedral angles, the separations of these atoms would be only 2.5 Å. Actually, intramolecular distances, C19---C20, C19---O3 and C20---O3, are 3.42 Å, 3.07 Å and 2.98 Å, respectively. The valence angles of C4-C5-C10 (118.5°), C5-C4-C19 (115.8°), C5-C10-C20 (115.2°), C6-C5-C10 (113.8°) and C4-C5-C6 (114.6°) are considerably different from the tetrahedral angles. The bond lengths of C4-C5 (1.57 Å), C5-C10 (1.56 Å), C1-C10 (1.56 Å) and C9-C10 (1.59 Å) are significantly longer than the average length of 1.53 Å for remaining single bonds in

Table 2. The final atomic coordinates.

Atom	x/a	y/b	z/c	Atom	x/a	y/b	z/c
C(1)	0.3643	0.0440	0.3377	C(14)	0.4808	0.0740	0.0517
C(2)	0.3651	-0.0217	0.4432	C(15)	0.5782	0.0686	-0.0029
C(3)	0.4649	-0.0059	0.5263	C(16)	0.5500	0.2156	0.0129
C(4)	0.4619	0.0866	0.5862	C(17)	0.3803	0.3688	0.2203
C(5)	0.4449	0.1551	0.4814	C(18)	0.5762	0.0992	0.6462
C(6)	0.4556	0.2495	0.5223	C(19)	0.3784	0.0894	0.6905
C(7)	0.4664	0.3104	0.4119	C(20)	0.2325	0.1506	0.4356
C(8)	0.3705	0.2995	0.3217	C(21)	0.3712	0.3301	0.6886
C(9)	0.3677	0.2040	0.2731	C(22)	0.2654	0.3584	0.7428
C(10)	0.3506	0.1391	0.3851	O(1)	0.4710	0.1854	0.2132
C(11)	0.2792	0.1925	0.1708	O(2)	0.6311	0.1478	-0.0239
C(12)	0.3430	0.2010	0.0520	O(3)	0.3582	0.2763	0.5921
C(13)	0.4590	0.1688	0.0824	O(4)	0.4572	0.3522	0.7205

Table 3. Bond distances and angles in a molecule.

Bond distances (Å)		Bond angles (°)		Bond angles (°)	
C1-C2	1.523	C2-C1-C10	112.1	C11-C9-O1	104.2
C1-C10	1.564	C1-C2-C3	109.0	C1-C10-C5	106.7
C2-C3	1.542	C2-C3-C4	111.7	C1-C10-C9	108.8
C3-C4	1.551	C3-C4-C5	108.1	C1-C10-C20	108.7
C4-C5	1.570	C3-C4-C18	105.2	C5-C10-C9	108.7
C4-C18	1.546	C3-C4-C19	111.3	C5-C10-C20	115.2
C4-C19	1.508	C5-C4-C18	109.7	C9-C10-C20	108.6
C5-C6	1.522	C5-C4-C19	115.8	C9-C11-C12	104.6
C5-C10	1.559	C18-C4-C19	106.2	C11-C12-C13	105.0
C6-C7	1.523	C4-C5-C6	114.6	C12-C13-C14	115.4
C6-O3	1.459	C4-C5-C10	118.5	C12-C13-C16	114.3
C7-C8	1.530	C6-C5-C10	113.8	C12-C13-O1	104.4
C8-C9	1.545	C5-C6-C7	111.1	C14-C13-C16	102.4
C8-C17	1.536	C5-C6-O3	110.5	C14-C13-O1	111.6
C9-C10	1.586	C7-C6-O3	108.1	C16-C13-O1	108.9
C9-C11	1.552	C6-C7-C8	111.3	C13-C14-C15	108.3
C9-O1	1.444	C7-C8-C9	109.7	C14-C15-O2	115.9
C10-C20	1.541	C7-C8-C17	108.8	C13-C16-O2	106.3
C11-C12	1.497	C9-C8-C17	114.5	C22-C21-O3	114.7
C12-C13	1.523	C8-C9-C10	109.6	C22-C21-O4	124.8
C13-C14	1.523	C8-C9-C11	112.0	O3-C21-O4	120.6
C13-C16	1.525	C8-C9-O1	109.1	C9-O1-C13	112.9
C13-O1	1.442	C10-C9-C11	112.6	C15-O2-C16	105.2
C14-C15	1.316	C10-C9-O1	109.1	C6-O3-C21	119.1
C15-O2	1.391				
C16-O2	1.490				
C21-C22	1.484				
C21-O3	1.327				
C21-O4	1.175				

rings A and B. Stretching of interatomic distances and distortion of bond angles are mainly due to strong steric strains which can be expected between $CH_3(19)$ and $CH_3(20)$, $CH_3(19)$ and O3, $CH_3(20)$ and O3, $CH_\beta(1)$ and $CH(11)^8$, and $CH_3(20)$ and $CH(11)^8$. The same type of bond distance lengthening effects have been found in crystal structures of levopimaric acid[9] and mebadonin.[10] The molecular packing is shown in Fig. 2. All the intermolecular approaches correspond to van der Waals interactions.

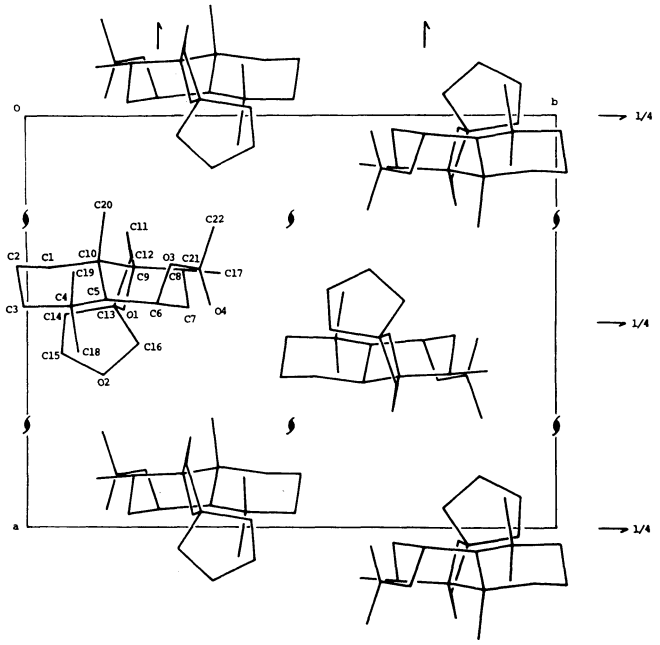


Figure 2. Molecular packing as viewed down the c axis.

Acknowledgement

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Footnotes and References

1. Y. Asaka, T. Kamikawa and T. Kubota, to be published in Chem. Lett..

2. Crystals were kindly supplied by Y. Asaka, T. Kamikawa and T. Kubota of this University.

3. M. M. Woolfson and G. Germain, Acta Crystallogr., B24, 91 (1968).

4. J. Karle and H. Hauptman, Acta Crystallogr., 9, 635 (1956).

5. $R(\text{Karle}) = \Sigma||Eo|-|Ec||/\Sigma|Eo|$

6. $Z = 2\sigma_3\sigma_2^{-3/2}\sum_h|E_h|\{(\sum_k|E_kE_{h-k}|\sin(\phi_k+\phi_{h-k}))^2+(\sum_k|E_kE_{h-k}|\cos(\phi_k+\phi_{h-k}))^2\}^{1/2}$

7. All calculations were performed on a FACOM 270/30 computer at the Computer Center of Osaka City University.

8. This H atom is on the same side of C14 with respect to the plane of ring C.

9. I. L. Karle, Acta Crystallogr., B28, 2000 (1972).

10. K. Hirotsu, T. Kamikawa, T. Kubota, A. Shimada and T. Isobe, Chem. Lett., 255 (1973).

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