

**(2*R*,3*R*,5*R*)-2-[(2*R*,3*aS*,6*aR*)-2,3,3*a*,
4,5,6*a*-Hexahydrofuro[2,3-*b*]furan-2-
yl]-5-isopropenyl-2,3-dimethylcyclo-
hexanone and (4*aR*,5*S*,7*R*)-5-isopro-
penyl-7,8,8-trimethyl-2,3,4,4*a*,
5,6,7,8-octahydronaphthalene-
4*a*-carbonitrile**

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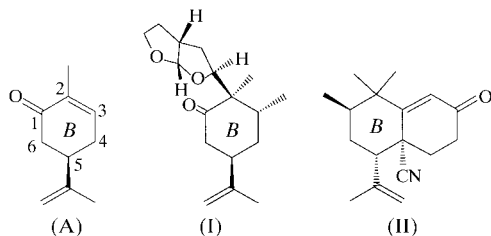
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The molecular structures of two chiral cyclohexanones based on *R*-(-)-carvone, C₁₇H₂₆O₃, (I), and C₁₇H₂₃NO, (II), are reported here. The six-membered ring in (I) is in a chair conformation with the two fused five-membered rings of the furofuranyl substituent in a *cis* configuration. Compound (II) contains a decalin group; one ring has the chair form whilst the other is in a half-boat conformation. Both products have been characterized spectroscopically, however, neither NMR nor IR results could prove the stereochemistry at each chiral centre unambiguously. The crystal analyses were used to examine conformational properties of the compounds.

Comment

Carvone [compound (A) in the Scheme] is a useful synthon which can be used as a starting material in the total synthesis of natural products. Surprisingly, only powder-diffraction



analyses of *L*- and *DL*-carvone have been reported (Sane *et al.*, 1997). Compounds containing this carvone core are easily modified to give flexible intermediates which retain the stereochemistry of the starting material. The configuration of the isopropenyl group at C5 determines the stereochemistry of the final product; the configuration at positions C2 and C3 is fixed in preceding reaction steps, irrespective of the reaction

conditions. Additionally, the isopropenyl group is readily removed and can subsequently be replaced with other functional groups, such as hydroxyl or double bonds.

The synthesis and analytical properties of (I) (Fig. 1) have been reported previously (Meulemans *et al.*, 1998). Initially, a 1:1 mixture of diastereoisomers, with respect to the orientation of the furofuranyl side chain, was obtained. The two diastereoisomers were separable upon crystallization since the second form can only be isolated as an oil. The six-membered carvone-type ring in (I) is in a chair conformation, with puckering parameters of $Q = 0.543$ (3) Å, $\theta = 3.7$ (3)° and $\varphi = 176$ (4)° (Evans & Boeyens, 1989; Spek, 2000). These values are comparable to substituted *S*-carvone ring systems (Spek *et al.*, 1990; Lutz & Spek, 1998); the weighted and unit r.m.s. deviations to the inverted ring atoms are in very good agreement, 0.027 and 0.025 Å, respectively. By comparison, the fit with the six-membered ring of 5(*R*)-isopropenyl-2-methyl-6(*R*)-[1(*R*)-methyl-2-nitroethyl]cyclohex-2-en-1-one (Johnston & Payne, 1981) is poorer; this ring resembles a half-boat conformation.

The *cis*-fused furan rings adopt envelope and twist conformations; the O2/C12/C9/C10/C11 ring has an envelope on C11, whereas the O3/C12/C9/C8/C7 ring is twisted about C17–C18 [puckering parameters $Q = 0.334$ (3) Å, $\theta = 331.1$ (5)° and $Q = 0.302$ (3) Å, $\theta = 130.8$ (5)°, respectively (Evans & Boeyens, 1989)]. The bonding parameters in the two furan rings are comparable, with C–O distances of 1.410 (4), 1.435 (4) Å, and 1.410 (3), 1.436 (3) Å. The stereochemistry at the chiral atoms is fixed: since C5 has to be *R*, the configuration at C3, C6, C7, C9 and C12 is *R*, *R*, *R*, *S* and *R*, respectively.

The synthesis and analytical properties of (II) (Fig. 2) have been reported previously (Jansen *et al.*, 2000). Functional groups are readily added at C2 in (I), corresponding to C6 in *R*-carvone, the cyano species being a good activator of carbonyl groups for condensation in the subsequent cyclization reaction (to construct the decalin system). The original carvone ring, as indicated by a *B* in the scheme, is in a chair conformation, whilst the second ring resembles the half-boat form [puckering parameters $Q = 0.494$ (3) Å, $\theta = 119.8$ (5)°

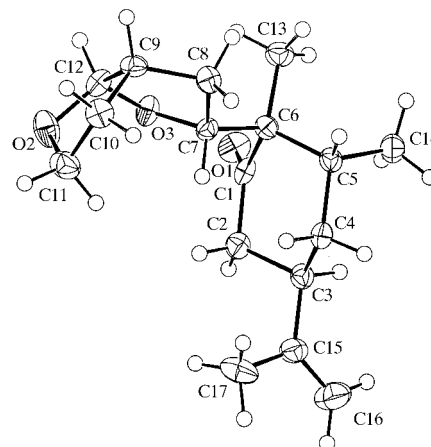


Figure 1

The displacement ellipsoid plot (PLATON; Spek, 2000) of (I) drawn at the 50% probability level.

and $\varphi = 358.2 (5)^\circ$ (Evans & Boeyens, 1989) for ring *B*; $Q = 0.533 (4) \text{ \AA}$, $\theta = 166.8 (4)^\circ$ and $\varphi = 292.2 (19)^\circ$ for the second ring]. Both rings show small deviations; ring *B* due to the restriction of fused atoms C5 and C10, whilst the second ring is additionally constrained by the enone functionality [C10—C1—C2—O1 = $168.8 (3)^\circ$], which flattens this end of the decalin moiety. The cyano species is linear, N1—C17—C5 = $174.6 (4)^\circ$, and is added on the same side as the isopropenyl group. Under the reaction conditions, the stereochemistry at the isopropenyl group (C6) is *S*; thus the configuration at the other chiral centres C5 and C8 is *R*.

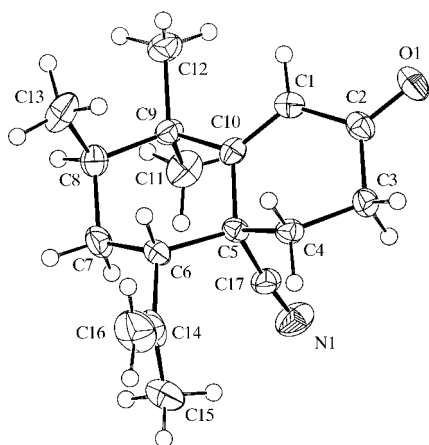


Figure 2
The displacement ellipsoid plot (PLATON; Spek, 2000) of (II) drawn at the 50% probability level.

The geometric parameters in (I) and (II) are fairly consistent, with the exception of the bond measurements in the isopropenyl group. The C=C of the isopropenyl group is shorter in compound (I) [$1.315 (4) \text{ \AA}$ compared to $1.381 (6) \text{ \AA}$ in (II)] and the C—C bond is corresponding longer [$1.506 (5) \text{ \AA}$ in (I) compared to $1.436 (6) \text{ \AA}$ in (II)], indicating a greater localization of charge in (I). The carbonyl groups have similar values [$1.213 (3)$ in (I) compared to $1.222 (4) \text{ \AA}$ in (II)]. All the C—C—C bond angles are within their normal ranges. Neither compound is stabilized by inter- or intramolecular hydrogen bonding since there are no suitable donor–acceptor interactions in the molecule. The shortest contacts are O1···H4Bⁱ of 2.43 , O2···H9ⁱⁱ of 2.82 and O3···H9ⁱⁱ of 2.65 \AA for compound (I), and O1···H3Aⁱⁱⁱ of 2.47 and N1···H4A^{iv} of 2.65 \AA for compound (II) [symmetry codes: (i) $1 + x, y, z$; (ii) $2 - x, \frac{1}{2} + y, \frac{1}{2} - z$; (iii) $\frac{1}{2} + x, \frac{1}{2} - y, -z$; (iv) $-x, \frac{1}{2} + y, \frac{1}{2} - z$].

Experimental

The synthesis of (I) has been described (Meulemans *et al.*, 1998). The diastereoisomer was separated on recrystallization from an isopropyl ether solution. The synthesis of (II) has been described (Jansen *et al.*, 2000). The compound was recrystallized from a *tert*-butyl methyl ether/pentane/methanol/water mixture.

Table 1

Selected geometric parameters (\AA , $^\circ$) for (I).

O1—C1	1.213 (3)	O3—C7	1.436 (3)
O2—C12	1.410 (4)	C15—C16	1.315 (4)
O2—C11	1.435 (4)	C15—C17	1.506 (5)
O3—C12	1.410 (3)		
C6—C1—C2—C3	$-53.1 (3)$	C3—C4—C5—C6	$56.5 (3)$
C1—C2—C3—C4	$52.3 (3)$	C2—C1—C6—C5	$50.9 (3)$
C2—C3—C4—C5	$-55.3 (3)$	C4—C5—C6—C1	$-50.9 (3)$

Compound (I)

Crystal data

C₁₇H₂₆O₃
 $M_r = 278.38$
 Orthorhombic, $P2_12_12_1$
 $a = 6.3914 (5) \text{ \AA}$
 $b = 9.0264 (6) \text{ \AA}$
 $c = 26.9292 (19) \text{ \AA}$
 $V = 1553.58 (19) \text{ \AA}^3$
 $Z = 4$
 $D_x = 1.190 \text{ Mg m}^{-3}$

Mo $K\alpha$ radiation
 Cell parameters from 25 reflections
 $\theta = 9.91\text{--}13.78^\circ$
 $\mu = 0.080 \text{ mm}^{-1}$
 $T = 150 (2) \text{ K}$
 Block, colourless
 $0.50 \times 0.30 \times 0.30 \text{ mm}$

Data collection

Enraf–Nonius CAD-4 diffractometer
 ω scans
 4168 measured reflections
 2084 independent reflections
 1522 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.050$

$\theta_{\text{max}} = 27.46^\circ$
 $h = -8 \rightarrow 0$
 $k = -11 \rightarrow 11$
 $l = -34 \rightarrow 0$
 3 standard reflections
 frequency: 60 min
 intensity decay: $<1\%$

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.048$
 $wR(F^2) = 0.114$
 $S = 0.951$
 2084 reflections
 184 parameters
 H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0559P)^2 + 0.1569P]$
 where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\text{max}} = 0.001$
 $\Delta\rho_{\text{max}} = 0.26 \text{ e \AA}^{-3}$
 $\Delta\rho_{\text{min}} = -0.24 \text{ e \AA}^{-3}$

Compound (II)

Crystal data

C₁₇H₂₃NO
 $M_r = 257.36$
 Orthorhombic, $P2_12_12_1$
 $a = 8.3419 (9) \text{ \AA}$
 $b = 12.3902 (10) \text{ \AA}$
 $c = 14.4052 (14) \text{ \AA}$
 $V = 1488.9 (2) \text{ \AA}^3$
 $Z = 4$
 $D_x = 1.148 \text{ Mg m}^{-3}$

Mo $K\alpha$ radiation
 Cell parameters from 25 reflections
 $\theta = 9.89\text{--}15.13^\circ$
 $\mu = 0.070 \text{ mm}^{-1}$
 $T = 150 (2) \text{ K}$
 Block, yellow
 $0.30 \times 0.30 \times 0.30 \text{ mm}$

Data collection

Enraf–Nonius CAD-4T diffractometer
 ω scans
 5872 measured reflections
 1534 independent reflections
 1059 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.100$

$\theta_{\text{max}} = 25.04^\circ$
 $h = 0 \rightarrow 9$
 $k = -14 \rightarrow 14$
 $l = -17 \rightarrow 17$
 3 standard reflections
 frequency: 60 min
 intensity decay: $<1\%$

Table 2
Selected geometric parameters (Å, °) for (II).

O1–C2	1.222 (4)	C14–C16	1.381 (6)
N1–C17	1.148 (4)	C14–C15	1.436 (6)
C1–C10	1.341 (5)		
N1–C17–C5	174.6 (4)		
C10–C1–C2–O1	168.8 (3)	C6–C7–C8–C9	59.3 (4)
C10–C1–C2–C3	–7.9 (5)	C7–C8–C9–C10	–48.7 (4)
C1–C2–C3–C4	–25.0 (4)	C2–C1–C10–C5	9.5 (5)
C2–C3–C4–C5	55.1 (4)	C8–C9–C10–C5	42.8 (4)
C3–C4–C5–C10	–53.4 (4)	C4–C5–C10–C1	21.1 (4)
C10–C5–C6–C7	50.7 (4)	C6–C5–C10–C9	–43.7 (4)
C5–C6–C7–C8	–60.6 (4)		

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.050$
 $wR(F^2) = 0.105$
 $S = 1.035$
 1534 reflections
 176 parameters
 H-atom parameters constrained

$$w = 1/[\sigma^2(F_o^2) + (0.0418P)^2 + 0.0185P]$$

where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\max} = 0.001$
 $\Delta\rho_{\max} = 0.16 \text{ e } \text{Å}^{-3}$
 $\Delta\rho_{\min} = -0.17 \text{ e } \text{Å}^{-3}$

Due to the absence of anomalous scatterers, the absolute configuration could not be established reliably (Flack & Bernardinelli, 1999). The *SHELXL97* values for the Flack x parameter (Flack, 1983) were 1 (2) and 2 (4) for (I) and (II), respectively. The absolute configuration was therefore chosen with respect to (*R*)-carvone, the starting material in the synthesis of both products. Under the reaction conditions, the configuration at the isopropenyl group [in (II)] becomes *S*. The number of Friedel pairs measured was 1484 (71% of the calculated total) and 1450 (74% of total) for data sets (I) and (II), respectively. The final refinement cycles were performed in which Friedel-related reflections have been merged. The R_{int} value in compound (II) is quite high (0.10) due to the number of weak data. All H atoms, except for those on methyl groups, were placed in idealized positions and constrained to ride on their C atoms (C–H 0.99–1.00 Å), with $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{C})$. The methyl H atoms were constrained to ideal geometries (C–H 0.95–0.98 Å), with $U_{\text{iso}}(\text{H}) = 1.5U_{\text{eq}}(\text{C})$, and allowed to rotate freely about their C–C bonds.

For both compounds, data collection: locally modified *CAD-4 Software* (Enraf–Nonius, 1989); cell refinement: *SET4* (de Boer & Duisenberg, 1984); data reduction: *HELENA* (Spek, 1997); program(s) used to solve structure: *SHELXS97* (Sheldrick, 1997); program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 2000); software used to prepare material for publication: *PLATON*.

Preliminary work for data set (I) was performed by the late Nora Veldman. Crystals were kindly provided by Dr T. M. Meulemans and Professor Dr A. de Groot, Wageningen University, The Netherlands. The investigations were supported by the Netherlands Foundation for Chemical Research (SON) with financial aid from the Netherlands Organization of Scientific Research (NWO).

Supplementary data for this paper are available from the IUCr electronic archives (Reference: GG1013). Services for accessing these data are described at the back of the journal.

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