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(8a*R*,*SS*)-Dimethyl 3,5,6,7,8,8a-hexahydro-4-{[(1*S*)-*exo*-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl]methylsulfinyl}-1,2-naphthalenedicarboxylate

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The title compound, $C_{24}H_{34}O_6S$, (I), is an enantiopure sulfinyl adduct, prepared *via* stereocontrolled Diels–Alder cycloaddition. The solid-state structure of (I) has been determined at room temperature by single-crystal X-ray diffraction. It is chemically similar to other cited structures; however, it presents a peculiar packing arrangement. *Ab initio*, density-functional theory (DFT) and semi-empirical (*AM*1, *PM*3 and *PM*5) full-geometry optimizations were carried out for (I). Calculated values of the structural parameters have been compared with those obtained by X-ray crystallography.

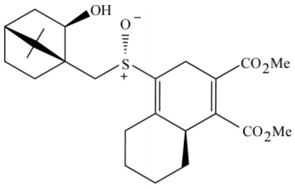
Key indicators

Single-crystal X-ray study
T = 298 K
Mean σ(C–C) = 0.007 Å
Disorder in main residue
R factor = 0.042
wR factor = 0.101
Data-to-parameter ratio = 9.4

For details of how these key indicators were automatically derived from the article, see http://journals.iucr.org/e.

Comment

The widespread presence of cyclic structures in the skeleton of natural molecules represents a main reason for the interest excited by reactions such as the Diels–Alder (DA) cycloaddition, which affords a straightforward access to molecules showing six-membered rings. The combination of DA reaction with asymmetric induction exerted by versatile sulfinyl auxiliaries represents a very powerful method for the formation of six-membered rings in a stereocontrolled manner (Aversa *et al.*, 1992, 1997, 1999). In the course of research on asymmetric DA syntheses involving enantiopure sulfinyl dienes, we investigated the reaction of (S_S)-1-{1-[(1*S*)-isoborneol-10-sulfinyl]vinyl}cyclohexene (Aversa *et al.*, 1998) with dimethyl acetylenedicarboxylate. The cycloaddition led to the formation of a 60:40 diastereomeric mixture of decalin-like adducts which represent versatile intermediates in the preparation of terpenoids (Boyer *et al.*, 2003). The two diastereoisomers (epimers at C8a) were easily separated by column chromatography, and the minor component, (I), crystallized from Et_2O–petrol (2:1 *v*/*v*) as colourless crystals, suitable for X-ray analysis, which permitted the assignment of the *R* configuration to the new stereogenic centre C8a, generated during the DA cycloaddition. In spite of the low diastereoselectivity observed in the studied cycloaddition, owing to the electronic and steric characteristics of the dienophile, the easy isolation of both cycloadducts, in enantiomerically pure form and good yield, assures the effectiveness of this synthetic approach.



(I)

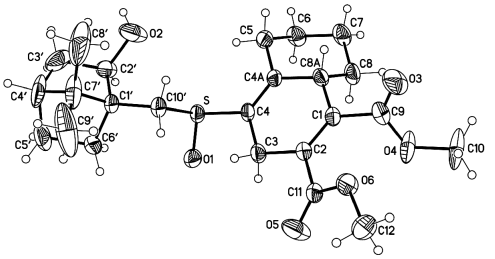


Figure 1
Molecular representation of (I), with 35% probability displacement ellipsoids representing all non-H atoms. The atom-numbering scheme is consistent with the systematic nomenclature numbering.

The structural resolution by X-ray diffraction of (I) as a unique asymmetric product is presented here. Previous similar structures determined by some of us have already been reported (Adams *et al.*, 1995; Aversa *et al.*, 1998); however, this structure displays peculiar packing aspects not evidenced so far. The structure of (I) was determined in order to assess its conformation and the configuration of the new chiral centres created by the cycloaddition reaction. The numbering scheme adopted is shown in Fig. 1. The conventional configuration of the chiral centres are: sulfur *S*; C1′ *S*; C2′ *R*; C4′ *R* and the new C8a *R*. The correct absolute configuration is determined by anomalous scattering, as evidenced by the Flack parameter [0.05 (10); Flack, 1983]. The isoborneol moiety adopts the typical conformation and, despite its rigidity, displacement parameters are rather large, probably because of the torsional freedom around the single C10′—C1′ bond. The hexahydronaphthalene moiety has the cyclohexadiene ring in an almost planar arrangement [maximum deviation from the mean plane for C3 of 0.042 (5) Å], while the other condensed ring adopts a chair (${}_5C^8$) conformation. In this sulfinyl adduct, unlike other analogous molecules (Aversa *et al.*, 1999), atom O2 does not act as a hydrogen-bond donor for an intramolecular interaction involving the S atom. The S atom, very close to O2 [S···O2 = 3.197 (2) Å], is involved in an intramolecular hydrogen bond with H5*B* (H5*B*···S 2.59 Å). On the other hand, the hydroxyl group has an intermolecular hydrogen-bond interaction, with sulfinyl atom O1 of an adjacent molecule acting as H-atom acceptor. These molecules, related by a simple translation along the crystallographic *a* axis, are bound together also by two other minor hydrogen-bond interactions (see Table 1 and Fig. 2). All these attractive interactions contribute to the development of monodimensional molecular arrays along the *a* axis. The chains formed by the three interactions generate peculiar ring structures; this can be described as $C_3^3(11)[R_2^2(13)[R_2^2(7)R_2^2(10)]]$ (Etter *et al.*, 1990). Inter-strand interactions are mainly of a hydrophobic nature.

Ab initio, density-functional theory (DFT), semi-empirical (*AM*1, *PM*3 and *PM*5) calculations and full-geometry optimizations were also carried out using *GAUSSIAN*98 (Frisch *et al.*, 1998) and *CaChe* (CaChe Chemistry Products, 2002) program packages. Different medium-level basis set were utilized in order to improve their reliability for reproducing the whole molecular geometry. More sophisticated calculations (such as *MP*2 or full basis set) are very resource-demanding due to the 31 non-H atoms of the molecule, so we have limited our calculations to those reported in Table 2. We observe an acceptable general agreement between the experimental X-ray structure and the calculated geometries. However, for semi-empirical calculations, the *PM*5 level seems to be the best method for reproducing the total molecular structure. Hartree–Fock minimizations at every level showed better results than the hybrid *B*3*LYP* method. DFT methods are known to be the best in reproducing the real molecular geometry; but which is the real structure and what are the best methods suitable to reproduce it? To answer this intriguing question we have in progress a project where we try to correlate the theoretical calculations (based on isolated molecules) with X-ray structural determinations in the solid state (as reported in the CSD), while recognizing the possible influence of the surrounding crystal packing.

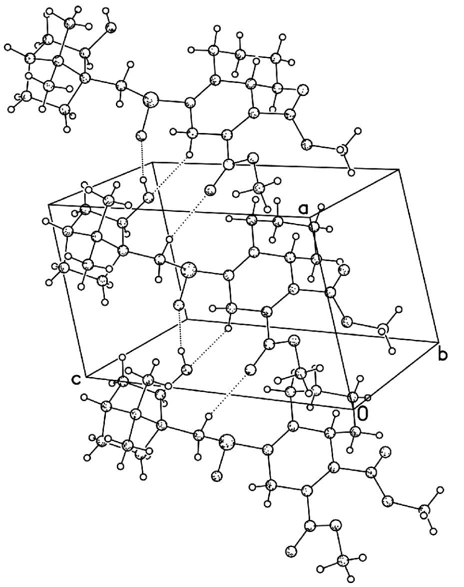


Figure 2
Molecular array along the crystallographic *a* axis, displaying the intermolecular hydrogen-bond interactions as dotted lines.

Experimental

Dimethyl acetylenedicarboxylate (0.981 ml, 7.98 mmol) was added to (S_S)-1-{1-[(1*S*)-isoborneol-10-sulfinyl]vinyl}cyclohexene (410 mg, 1.33 mmol), previously dissolved in 1,2-dichloroethane (10 ml). After refluxing for 26 h, the solvent was removed under reduced pressure. Column chromatography of the crude product mixture was carried

Table 1
Hydrogen-bonding geometry (Å, °).

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
C5—H5*B*···S	0.97	2.59	3.117 (4)	114
O2—H2*A*···O1^{i}	0.82	1.88	2.683 (5)	166
C10′—H10H···O5^{i}	0.97	2.59	3.534 (6)	166
C3—H3*B*···O2^{ii}	0.97	2.36	3.191 (6)	143
C10—H10*D*···O3	0.96	2.21	2.652 (9)	107
C8′—H8′1···O2	0.96	2.37	3.01 (1)	123
C8′—H8′6···O2	0.96	2.37	3.01 (1)	123

Symmetry codes: (i) $1 + x, y, z$; (ii) $x - 1, y, z$.

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Table 2
Selected interatomic distances (Å), bond angles and torsion angles (°) for (I). X-ray diffraction determination is compared to several computations (*AM*1, *PM*3, *PM*5, HF and DFT).

Parameter	X-ray	*AM*1	*PM*3	*PM*5	HF[a]	HF[b]	DFT[c]	DFT[b]
S—O1	1.501 (3)	1.4912	1.5566	1.4873	1.5014	1.4993	1.5249	1.5264
S—C4	1.804 (3)	1.7221	1.8145	1.7590	1.7809	1.8030	1.8364	1.8319
S—C10′	1.812 (3)	1.7693	1.8575	1.8040	1.7993	1.8179	1.8646	1.8622
O2—C2′	1.423 (5)	1.4167	1.4114	1.3957	1.4518	1.4100	1.4385	1.4381
C1′—C10′	1.520 (5)	1.4943	1.5105	1.5022	1.5214	1.5275	1.5225	1.5231
S···O2	3.197 (5)	3.4603	3.6651	3.4167	3.2662	3.4206	3.3863	3.4497
C9···O6	2.657 (6)	3.1760	3.3648	2.8242	3.7293	3.4915	2.9644	3.0893
C11···O4	3.136 (5)	2.8178	3.1848	2.7596	2.5298	2.5400	2.8309	2.7738
O1—S—C4	106.6 (2)	105.72	105.13	106.63	105.84	105.50	106.23	105.90
O1—S—C10′	107.1 (2)	105.09	104.15	105.97	106.82	106.22	107.60	107.52
C4—S—C10′	97.9 (2)	99.56	97.29	97.00	98.07	98.27	97.24	96.58
O2—C2′—C1′	110.2 (4)	110.39	111.17	110.31	109.50	110.97	110.52	110.77
O1—S—C4—C4*A*	138.0 (3)	173.06	167.78	165.70	164.68	157.80	160.41	154.12
C2—C1—C9—O3	−119.1 (6)	−138.81	−111.45	−132.68	−78.74	174.03	−131.77	−123.21
C1—C2—C11—O5	−157.2(5)	−114.96	−99.90	−128.17	175.70	−81.27	−140.10	−143.53
C2′—C1′—C10′—S	−53.0(5)	−63.51	−67.71	−58.12	−36.43	−59.53	−57.04	−58.49
C4—S—C10′—C1′	175.7(3)	168.49	164.42	177.55	173.93	175.06	175.67	179.58

Notes: (*a*) 3-21*G**, (*b*) 6-31+G(*d,p*), (*c*) 6-31*G*(*d*).

out on silica gel with petrol containing 60–70% EtOAc as eluant. The first eluted fraction was the sulfinyl adduct, (I), which was isolated as a solid (32% yield). This minor component crystallized from Et_2O–petrol (2:1 *v*/*v*).

Crystal data

$C_{24}H_{34}O_6S$
$M_r = 450.57$
Triclinic, *P*1
$a = 6.8037$ (6) Å
$b = 7.7391$ (8) Å
$c = 11.9131$ (9) Å
$\alpha = 84.539$ (8)°
$\beta = 74.277$ (6)°
$\gamma = 78.323$ (7)°
$V = 590.77$ (9) Å^3
$Z = 1$
$D_x = 1.266$ Mg m^{-3}
Mo *Kα* radiation
Cell parameters from 62 reflections
$\theta = 5.1$–20.0°
$\mu = 0.17$ mm^{-1}
$T = 298$ (2) K
Prism, colourless
0.46 × 0.32 × 0.28 mm

Data collection

Bruker *P*4 diffractometer
$2\theta/\omega$ scans
Absorption correction: none
2643 measured reflections
2642 independent reflections
2244 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.008$
$\theta_{\rm max} = 25°$
$h = -8 \rightarrow 1$
$k = -9 \rightarrow 9$
$l = -14 \rightarrow 13$
3 standard reflections every 197 reflections intensity decay: 1%

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.042$
$wR(F^2) = 0.101$
$S = 1.02$
2642 reflections
281 parameters
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0439P)^2 + 0.1716P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.19$ e Å^{-3}
$\Delta\rho_{\rm min} = -0.23$ e Å^{-3}
Extinction correction: *SHELXL*
Extinction coefficient: 0.019 (4)
Absolute structure: Flack (1983)
Flack parameter = 0.05 (10)

All H atoms were found in Fourier difference maps and were then placed in idealized positions and refined using the riding-model technique (idealized geometry and isotropic displacement parameters depended on the parent atom type). For disordered methyl groups C8′ C9′ and C10, two orientations were found (rotated by 60° from one another) for the three H atoms whose site-occupation factor was fixed at 0.5.

Data collection: *XSCANS* (Siemens, 1989); cell refinement: *XSCANS*; data reduction: *XPREPW* (Bruker, 1997); program(s) used to solve structure: *SIR*97 (Altomare *et al.*, 1994); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *XPW* (Bruker, 1997) and *ORTEP*-3 *for Windows* (Farrugia, 1997); software used to prepare material for publication: *PARST*97 (Nardelli, 1995) and *WinGX* (PC Version 1.6.4.05; Farrugia, 1999).

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References

Adams, H., Bailey, N. A., Jones, D. N., Aversa, M. C., Bonaccorsi, P. & Giannetto, P. (1995). *Acta Cryst.* C**51**, 1357–1359.
Altomare, A., Cascarano, G., Giacovazzo, C., Guagliardi, A., Burla, M. C., Polidori, G. & Camalli, M. (1994). *J. Appl. Cryst.* **27**, 435.
Aversa, M. C., Barattucci, A., Bonaccorsi, P., Giannetto, P. & Jones, D. N. (1997). *J. Org. Chem.* **62**, 4376–4384.
Aversa, M. C., Barattucci, A., Bonaccorsi, P., Giannetto, P. & Nicoló, F. (1999). *J. Org. Chem.* **64**, 2114–2118.
Aversa, M. C., Bonaccorsi, P., Giannetto, P., Jafari, S. M. A. & Jones, D. N. (1992). *Tetrahedron Asymmetry*, **3**, 701–704.
Aversa, M. C., Bonaccorsi, P., Giannetto, P., Panzalorto, M. & Rizzo, S. (1998). *Tetrahedron Asymmetry*, **9**, 1577–1587.
Boyer, F. D., Prange, T. & Ducrot, P.-H. (2003). *Tetrahedron Asymmetry*, **14**, 1153–1159.
Bruker (1997). *XPREPW* (Version 5.1/NT) and *XPW* (Version 5.1/NT). Bruker AXS Inc., Madison, Wisconsin, USA.
CAChe Chemistry Products (2002). *CaChe*. Version 5.03. CAChe Chemistry Products, Oxford, England.
Etter, M. C., MacDonald, J. C. & Bernstein, J. (1990). *Acta Cryst.* B**46**, 256–262.
Farrugia, L. J. (1997). *J. Appl. Cryst.* **30**, 565.
Farrugia, L. J. (1999). *J. Appl. Cryst.* **32**, 837–838.
Flack, H. D. (1983). *Acta Cryst.* A**39**, 876–881.
Frisch, M. J., Trucks, G. W., Schlegel, H. B., Scuseria, G. E., Robb, M. A., Cheeseman, J. R., Zakrzewski, V. G., Montgomery, J. A. Jr, Stratmann, R. E., Burant, J. C. *et al.* (1998). *GAUSSIAN*98. Revision A7. Gaussian Inc., Pittsburgh, Pennsylvania, USA.
Nardelli, M. (1995). *J. Appl. Cryst.* **28**, 659.
Sheldrick, G. M. (1997). *SHELXL*97. University of Göttingen, Germany.
Siemens (1989). *XSCANS*. Version 2.2. Siemens Analytical X-ray Instruments Inc., Madison, Wisconsin, USA.

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