$S = 1.58$
903 reflections
153 parameters
H-atom parameters not refined
$w = 4F_o^2/\sigma^2(F_o^2)$

Extinction correction: none
Atomic scattering factors from *International Tables for X-ray Crystallography* (1974, Vol. IV)

Table 1. *Fractional atomic coordinates and equivalent isotropic displacement parameters* (Å²)

$$B_{\rm eq} = (8\pi^2/3)\Sigma_i\Sigma_jU_{ij}a_i^*a_j^*\mathbf{a}_i.\mathbf{a}_j.$$

	x	y	z	$B_{\rm eq}$
Cl(1)	−0.0126 (3)	0.0127	0.1317 (2)	3.54 (7)
O(1)	0.0097 (8)	0.0212 (6)	0.8255 (4)	3.3 (2)
O(2)	0.367 (1)	−0.0701 (5)	0.9251 (5)	3.0 (2)
O(3)	0.041 (1)	0.7121 (6)	0.5370 (5)	4.6 (3)
O(4)	0.319 (1)	0.8451 (6)	0.6356 (6)	4.8 (3)
N(1)	0.462 (1)	0.1588 (6)	1.0588 (5)	2.4 (2)
N(2)	0.538 (1)	0.4254 (7)	0.6626 (6)	3.0 (3)
N(3)	0.150 (1)	0.4673 (6)	0.5386 (6)	3.7 (3)
N(4)	0.417 (1)	0.6366 (6)	0.6493 (5)	2.7 (2)
N(5)	0.252 (1)	0.7310 (7)	0.6052 (5)	3.1 (3)
C(1)	0.235 (1)	0.0236 (9)	0.8959 (5)	2.4 (3)
C(2)	0.320 (1)	0.1631 (7)	0.9301 (6)	2.1 (2)
C(3)	0.492 (1)	0.2164 (7)	0.8527 (6)	2.7 (3)
C(4)	0.369 (1)	0.2132 (8)	0.7206 (6)	2.9 (3)
C(5)	0.525 (1)	0.2816 (9)	0.6427 (7)	3.3 (3)
C(6)	0.356 (1)	0.511 (1)	0.6138 (5)	2.7 (3)
C(7)	0.110 (2)	−0.121 (2)	0.793 (1)	9.2 (8)

Table 2. *Selected geometric parameters* (Å, °)

O(1)—C(1)	1.310 (7)	N(3)—C(6)	1.327 (8)
O(1)—C(7)	1.59 (2)	N(4)—N(5)	1.328 (8)
O(2)—C(1)	1.190 (9)	N(4)—C(6)	1.35 (1)
O(3)—N(5)	1.251 (7)	C(1)—C(2)	1.51 (1)
O(4)—N(5)	1.236 (8)	C(2)—C(3)	1.52 (1)
N(1)—C(2)	1.505 (8)	C(3)—C(4)	1.513 (9)
N(2)—C(5)	1.47 (1)	C(4)—C(5)	1.53 (1)
N(2)—C(6)	1.335 (9)		
C(1)—O(1)—C(7)	116.1 (7)	N(1)—C(2)—C(1)	106.7 (5)
C(5)—N(2)—C(6)	124.6 (7)	N(1)—C(2)—C(3)	109.8 (5)
N(5)—N(4)—C(6)	117.6 (5)	C(1)—C(2)—C(3)	111.7 (5)
O(3)—N(5)—O(4)	119.3 (7)	C(2)—C(3)—C(4)	112.8 (5)
O(3)—N(5)—N(4)	125.0 (6)	C(3)—C(4)—C(5)	113.6 (6)
O(4)—N(5)—N(4)	115.6 (6)	N(2)—C(5)—C(4)	111.7 (7)
O(1)—C(1)—O(2)	125.6 (8)	N(2)—C(6)—N(3)	119.8 (8)
O(1)—C(1)—C(2)	111.5 (7)	N(2)—C(6)—N(4)	111.9 (6)
O(2)—C(1)—C(2)	122.8 (5)	N(3)—C(6)—N(4)	128.3 (7)

D—H···A	H···A	D···A
N(1)—H(1A)···O(2$^{\rm i}$)	1.94	2.886 (7)
N(1)—H(1B)···Cl(1$^{\rm ii}$)	2.40	3.244 (6)
N(1)—H(1C)···Cl(1$^{\rm iii}$)	2.25	3.158 (6)
N(2)—H(2)···Cl(1$^{\rm iv}$)	2.25	3.205 (6)
N(3)—H(3A)···O(3$^{\rm v}$)	1.93	2.843 (8)

Symmetry codes: (i) $1-x, \frac{1}{2}+y, 2-z$; (ii) $x, y, 1+z$; (iii) $1+x, y, 1+z$; (iv) $1-x, \frac{1}{2}+y, 1-z$; (v) $-x, y-\frac{1}{2}, 1-z$.

The positions of H atoms on N(2) and C(7) could not be located from difference Fourier synthesis and so were calculated geometrically. Other H atoms were subsequently located from difference Fourier synthesis and not refined.

Programs used for data collection and cell refinement: *MSC/AFC Data Collection and Refinement Software* (Rigaku Corporation, 1988). Programs used to solve structure: *SHELXS86* (Sheldrick, 1985); *DIRDIF* (Beurskens, 1984). All calculations including data reduction: *TEXSAN* (Molecular Structure Corporation, 1985).

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates, complete geometry and torsion angles have been deposited with the IUCr (Reference: AS1106). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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Structural Studies of Intermediates in the Synthesis of Mifepristone (RU 486). I. An 11β-Substituted Steroid

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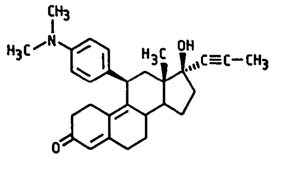
Abstract

The title compound, 11β-[4-(dimethylamino)phenyl]-3,3-(ethylenedioxy)-17α-(1-propynyl)estra-9-en-5α,17β-diol ($C_{31}H_{41}NO_4$), is the key intermediate in the synthesis of RU 486 and its overall conformation is similar to that of RU 486. The orientation of the (dimethylamino)phenyl ring, which seems to be con-

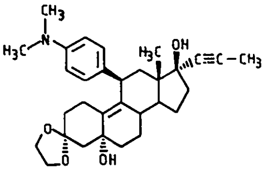
nected with agonistic or antagonistic activity, is perpendicular to the steroid skeleton and is coplanar with C(9)—C(11). The separation [O(1)···O(3)] between the terminal O atoms is 10.27 Å. The molecules are hydrogen bonded in a more or less head-to-tail fashion through H[O(3)] and O(4).

Comment

A few years ago Roussel-Uclaf (Paris) showed that 19-norsteroids substituted with a phenyl group at the 11β position possess anti-progestational activity (Belanger, Philibert & Teutsch, 1981). One of these compounds, RU 486 (I), has been tested in several clinical trials for the termination of early pregnancy and is the first steroidal antiprogesterone drug for non-surgical abortion in clinical use (Ulmann & Dubois, 1989; Heikinheimo, Ylikorkala & Lahteenmaki, 1990).



(I)



(II)

The title compound (II) is the key intermediate in the synthesis of RU 486. We undertook its crystal structure analysis to gain insight into the successive reaction pathways and to support an investigation aimed at finding more potent drugs with the same pharmacological profile. The conformation of the steroid molecule with atom numbering is shown in Fig. 1.

Bond lengths and bond angles in (II) are close to the expected values. The average C—C single-bond lengths in rings *A*, *C* and *D* are 1.530 (3), 1.534 (2) and 1.551 (2) Å, respectively. The mean C—C single-bond length in the whole molecule is 1.529 (4) Å. This is in agreement with values found in similar steroid structures (Griffin, Duax & Weeks, 1984; Palmer, Palmer, Lisgarten & Lancaster, 1993) including those cited by Allen, Kennard, Watson, Brammer, Orpen & Taylor (1987).

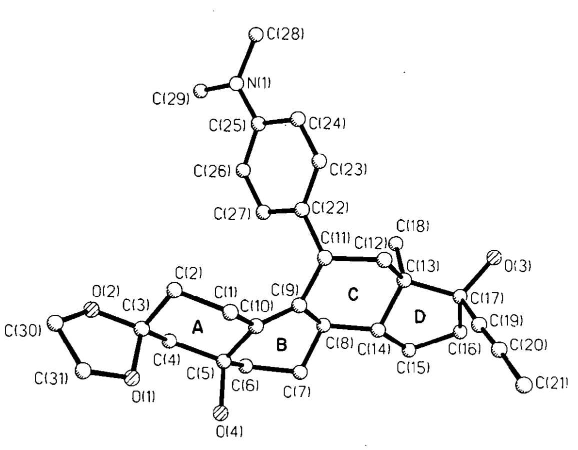


Fig. 1. Perspective view of the title molecule showing the labelling of the non-H atoms.

It is interesting to note that in the saturated ring *A* of (II), where a dioxyethylene protecting group is attached to C(3), the C(2)—C(3)—C(4) angle is 110.9 (4)°. This angle is enlarged to 116.2 (2)° when a carbonyl substituent is present (Roszak & Codding, 1990) but remains the same [110.6 (3)°] with a hydroxyl substituent (Palmer, Palmer, Lisgarten & Lancaster, 1993). In the saturated unsubstituted ring *A* of androstan-17-one (Banerjee, Das & Saenger, 1978) this angle is 109.9 (3)°. The effect of a subtituent at C(3) on the geometry of ring *A* is thus reflected by the bond angles.

The overall shape of ring *A* is, nevertheless, still approximately the chair conformation typical of such totally saturated rings. The conformational features of (II) may be described in terms of torsion angles and ΔC_s and ΔC_2 asymmetry parameters (Duax & Norton, 1975) (Table 2). Ring *A* has an ideal chair conformation. The Δ^9 ring *B* has a 6β,7α-half-chair conformation. As in 5β-dihydrotestosterone (Roszak & Codding, 1990), ring *C* has an unusual distorted chair form as a result of the strain at the junction with the five-membered ring *D* [C(12)—C(13)—C(14)—C(8) = 63.6 (5)°]. A similar conformation for ring *C* is observed in RU 486 (van Geerestein, Kanters, Sluis & Kroon, 1986) and ORG 761, an analogue of RU 486 (van Geerestein, Kanters & Kroon, 1987). The conformation of ring *D* is almost an ideal 13β envelope, similar to that found for RU 486 but slightly different from that of ORG 761; here ring *D* is reported to have a 13β,14α-half-chair conformation.

It is worthwhile mentioning that the antagonistic activity of RU 486 is due to the 11β-(dimethylamino)phenyl substituent and all steroids with aromatic 11β substituents are antagonists of transcription induced by human progesterone (Benhamou *et al.*, 1992). Hence, the positioning of the aromatic 11β substituent in the progesterone-receptor-hormone binding domain appears to be critical for generating agonistic or antagonistic activity. The orientation of the 11β-[4-(dimethylamino)phenyl] group in the title compound is perpendicular to the steroid skeleton; a similar orientation of the (dimethylamino)phenyl group is observed in both RU 486 and ORG 761. Also, this group is coplanar with C(9)—C(11), as indicated by the C(9)—C(11)—C(22)—C(23) torsion angle of 179.9 (5)°. The torsion angles C(29)—N(1)—C(25)—C(26) and C(28)—N(1)—C(25)—C(24) [−3.4 (5) and 6.0 (8)°, respectively] show that the amino group is significantly distorted both from planarity and from coplanarity with the phenyl ring; N(1), C(28) and C(29) deviate from the mean phenyl ring plane by −0.08 (1), 0.01 (1) and −0.06 (1) Å, respectively. The orientation of the propynyl group is illustrated by the torsion angle C(15)—C(16)—C(17)—C(19) of 96.7 (6)° [−93.8 (4) for RU 486 and −103.3 (5)° for ORG 761].

Fig. 2 illustrates the superposition obtained by a least-squares fit [using the *OFIT* option in the *SHELXTL-Plus* (Sheldrick, 1990) graphics program] of the steroid skeletons [atoms C(1) to C(18)] of the title compound, RU 486 and ORG 761. The separation [O(1)···O(3)] between the terminal O atoms is 10.27 in the title compound, 10.96 in RU 486 and 10.82 Å in ORG 761.

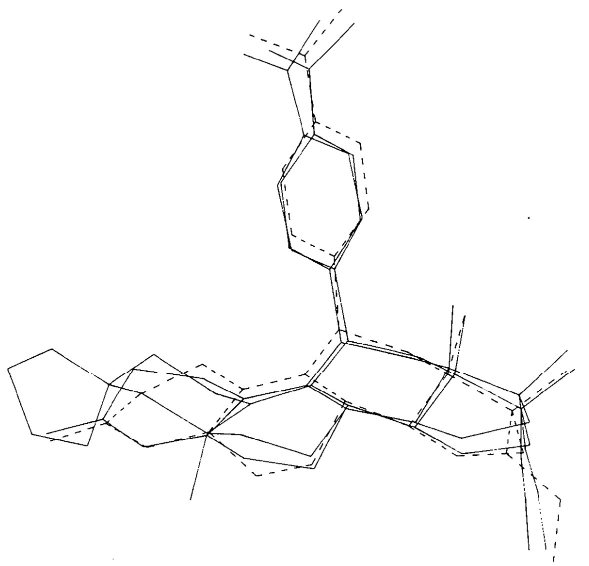


Fig. 2. Least-squares fit of the title molecule (thin line) with molecules of RU 486 (thin line) and ORG 761 (dashed line).

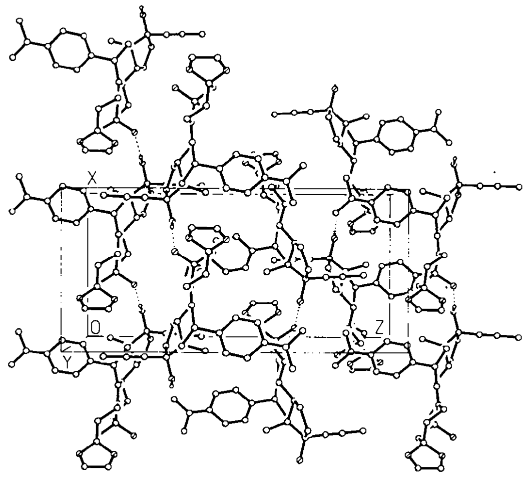


Fig. 3. Molecular packing in the unit cell viewed down the [010] axis. H atoms except H[O(3)] are omitted for clarity. Dashed lines indicate the O(3)—H···O(4) interaction.

The molecular packing is shown in Fig. 3. The steroid molecules form a head-to-tail hydrogen-bonding pattern: O(3)···O(4)($x-1$, y, z) = 3.025 (6) Å and O(3)—H···O(4) = 161.6 (5)°. The presence of an O(4) hydroxyl group at C(5) favours an intramolecular hydrogen bond with one of the O atoms [O(1)] of the dioxyethylene group [O(4)···O(1) = 2.772 (5) Å and O(4)—H···O(1) = 145.2 (4)°].

Experimental

The title compound was prepared by a multi-step synthesis according to the method of Belanger, Philibert & Teutsch (1981), and was recrystallized from ethyl acetate.

Crystal data

$C_{31}H_{41}NO_4$
$M_r = 491.7$
Orthorhombic
$P2_12_12_1$
$a = 9.997$ (2) Å
$b = 12.780$ (2) Å
$c = 21.163$ (4) Å
$V = 2703.8$ (9) Å^3
$Z = 4$
$D_x = 1.208$ Mg m^{-3}

Mo $K\alpha$ radiation
$\lambda = 0.71069$ Å
Cell parameters from 25 reflections
$\theta = 4$–19°
$\mu = 0.074$ mm^{-1}
$T = 294$ K
Cubes
0.28 × 0.24 × 0.20 mm
Transparent

Data collection

Siemens $R3m/V$ diffractometer
ω–2θ scans
Absorption correction: none
2068 measured reflections
2047 independent reflections
1631 observed reflections [$I \geq 3\sigma(I)$]

$\theta_{\max} = 22.5°$
$h = 0 \rightarrow 10$
$k = 0 \rightarrow 13$
$l = 0 \rightarrow 22$
2 standard reflections monitored every 98 reflections intensity variation: <1%

Refinement

Refinement on F
$R = 0.048$
$wR = 0.051$
$S = 1.38$
1631 reflections
325 parameters
$w = 1/[\sigma^2(F) + 0.0012F^2]$

$(\Delta/\sigma)_{\max} = 0.001$
$\Delta\rho_{\max} = 0.21$ e Å^{-3}
$\Delta\rho_{\min} = -0.18$ e Å^{-3}
Atomic scattering factors from *SHELXTL-Plus* (Sheldrick, 1990)

Table 1. *Fractional atomic coordinates and equivalent isotropic displacement parameters* (Å^2)

$U_{eq} = (1/3)\Sigma_i\Sigma_jU_{ij}a_i^*a_j^*\mathbf{a}_i.\mathbf{a}_j.$

	x	y	z	U_{eq}
O(1)	0.2007 (4)	0.3914 (3)	0.6281 (2)	0.049 (1)
O(2)	0.1926 (4)	0.3685 (3)	0.5231 (2)	0.054 (1)
O(3)	−0.6977 (4)	0.7660 (3)	0.6919 (2)	0.058 (1)
O(4)	0.1156 (4)	0.5813 (3)	0.6769 (2)	0.045 (1)
N(1)	−0.4582 (5)	0.4545 (4)	0.3526 (2)	0.058 (2)
C(1)	−0.0925 (6)	0.4173 (4)	0.6353 (3)	0.046 (2)
C(2)	−0.0172 (5)	0.3673 (5)	0.5800 (3)	0.047 (2)
C(3)	0.1213 (5)	0.4134 (4)	0.5737 (2)	0.039 (2)
C(4)	0.1145 (5)	0.5316 (4)	0.5655 (2)	0.040 (2)
C(5)	0.0353 (5)	0.5883 (4)	0.6193 (2)	0.034 (2)

C(6)	0.0214 (6)	0.7032 (4)	0.6042 (3)	0.043 (2)
C(7)	−0.0850 (5)	0.7533 (4)	0.6461 (2)	0.041 (2)
C(8)	−0.2211 (5)	0.7084 (4)	0.6290 (2)	0.036 (2)
C(9)	−0.2170 (5)	0.5882 (4)	0.6262 (2)	0.030 (2)
C(10)	−0.1010 (5)	0.5357 (4)	0.6284 (2)	0.031 (2)
C(11)	−0.3521 (5)	0.5345 (4)	0.6164 (2)	0.032 (2)
C(12)	−0.4679 (5)	0.5826 (4)	0.6556 (2)	0.036 (2)
C(13)	−0.4712 (5)	0.7015 (4)	0.6554 (2)	0.037 (2)
C(14)	−0.3305 (5)	0.7395 (4)	0.6753 (2)	0.039 (2)
C(15)	−0.3534 (6)	0.8571 (5)	0.6903 (3)	0.057 (2)
C(16)	−0.4976 (6)	0.8657 (5)	0.7138 (3)	0.056 (2)
C(17)	−0.5593 (6)	0.7536 (5)	0.7076 (3)	0.044 (2)
C(18)	−0.5158 (6)	0.7440 (5)	0.5912 (2)	0.045 (2)
C(19)	−0.5504 (6)	0.6996 (5)	0.7698 (3)	0.047 (2)
C(20)	−0.5484 (6)	0.6612 (5)	0.8217 (3)	0.055 (2)
C(21)	−0.5404 (8)	0.6157 (7)	0.8862 (3)	0.084 (3)
C(22)	−0.3818 (5)	0.5214 (4)	0.5456 (2)	0.035 (2)
C(23)	−0.4995 (6)	0.4743 (5)	0.5257 (2)	0.043 (2)
C(24)	−0.5272 (6)	0.4529 (5)	0.4633 (2)	0.048 (2)
C(25)	−0.4348 (6)	0.4797 (4)	0.4150 (2)	0.041 (2)
C(26)	−0.3185 (6)	0.5305 (5)	0.4346 (2)	0.043 (2)
C(27)	−0.2915 (6)	0.5509 (4)	0.4977 (2)	0.039 (2)
C(28)	−0.5856 (7)	0.4083 (6)	0.3342 (3)	0.064 (3)
C(29)	−0.3629 (7)	0.4864 (6)	0.3047 (3)	0.068 (3)
C(30)	0.2541 (7)	0.2740 (5)	0.5471 (3)	0.063 (3)
C(31)	0.2586 (7)	0.2912 (5)	0.6176 (3)	0.072 (3)

Table 2. *Bond lengths* (Å), *bond angles* (°), *selected torsion angles* (°) *and asymmetry parameters* (°)

O(1)—C(3)	1.427 (6)	O(1)—C(31)	1.422 (8)
O(2)—C(3)	1.409 (6)	O(2)—C(30)	1.447 (8)
O(3)—C(17)	1.432 (7)	O(4)—C(5)	1.463 (6)
N(1)—C(25)	1.380 (7)	N(1)—C(28)	1.457 (8)
N(1)—C(29)	1.449 (8)	C(1)—C(2)	1.532 (8)
C(1)—C(10)	1.522 (8)	C(2)—C(3)	1.510 (8)
C(3)—C(4)	1.522 (8)	C(4)—C(5)	1.564 (7)
C(5)—C(6)	1.509 (8)	C(5)—C(10)	1.531 (7)
C(6)—C(7)	1.526 (8)	C(7)—C(8)	1.520 (8)
C(8)—C(9)	1.538 (7)	C(8)—C(14)	1.521 (7)
C(9)—C(10)	1.341 (7)	C(9)—C(11)	1.529 (7)
C(11)—C(12)	1.551 (7)	C(11)—C(22)	1.536 (7)
C(12)—C(13)	1.519 (8)	C(13)—C(14)	1.546 (8)
C(13)—C(17)	1.563 (8)	C(13)—C(18)	1.530 (7)
C(14)—C(15)	1.554 (8)	C(15)—C(16)	1.529 (9)
C(16)—C(17)	1.566 (9)	C(17)—C(19)	1.489 (8)
C(19)—C(20)	1.203 (9)	C(20)—C(21)	1.486 (9)
C(22)—C(23)	1.387 (8)	C(22)—C(27)	1.409 (7)
C(23)—C(24)	1.378 (7)	C(24)—C(25)	1.419 (8)
C(25)—C(26)	1.395 (8)	C(26)—C(27)	1.388 (7)
C(30)—C(31)	1.509 (9)		

C(3)—O(1)—C(31)	106.1 (4)	C(11)—C(12)—C(13)	114.2 (4)
C(28)—N(1)—C(29)	120.1 (5)	C(12)—C(13)—C(17)	115.8 (4)
C(25)—N(1)—C(28)	119.9 (5)	C(17)—C(13)—C(18)	108.2 (4)
C(1)—C(2)—C(3)	110.8 (5)	C(14)—C(13)—C(17)	100.7 (4)
O(1)—C(3)—C(2)	111.2 (4)	C(13)—C(14)—C(15)	103.1 (4)
C(2)—C(3)—C(4)	110.9 (4)	C(14)—C(15)—C(16)	105.9 (5)
O(1)—C(3)—C(4)	108.2 (4)	C(13)—C(17)—C(16)	103.1 (4)
O(4)—C(5)—C(4)	107.5 (4)	O(3)—C(17)—C(13)	115.3 (4)
C(4)—C(5)—C(6)	110.1 (4)	C(13)—C(17)—C(19)	113.2 (5)
O(4)—C(5)—C(6)	106.6 (4)	C(17)—C(19)—C(20)	175.6 (6)
C(5)—C(6)—C(7)	110.5 (4)	C(11)—C(22)—C(27)	123.2 (5)
C(7)—C(8)—C(14)	113.1 (4)	C(23)—C(22)—C(27)	116.2 (5)
C(9)—C(8)—C(14)	107.8 (4)	C(23)—C(24)—C(25)	120.8 (5)
C(8)—C(9)—C(10)	121.4 (5)	C(24)—C(25)—C(26)	116.2 (5)
C(5)—C(10)—C(9)	123.1 (5)	C(25)—C(26)—C(27)	122.4 (5)
C(1)—C(10)—C(5)	113.5 (5)	O(2)—C(30)—C(31)	103.7 (5)
C(3)—O(2)—C(30)	106.8 (4)	C(12)—C(11)—C(22)	114.9 (4)
C(25)—N(1)—C(29)	119.5 (5)	C(12)—C(13)—C18)	111.4 (4)
C(2)—C(1)—C(10)	111.7 (5)	C(12)—C(13)—C(14)	107.0 (4)
O(2)—C(3)—C(2)	111.8 (4)	C(14)—C(13)—C(18)	113.3 (4)
O(1)—C(3)—O(2)	104.5 (4)	C(8)—C(14)—C(13)	113.4 (4)
O(2)—C(3)—C(4)	109.9 (4)	C(8)—C(14)—C(15)	119.3 (5)
C(3)—C(4)—C(5)	113.5 (4)	C(15)—C(16)—C(17)	106.2 (5)
C(4)—C(5)—C(10)	109.9 (4)	O(3)—C(17)—C(16)	107.4 (4)
O(4)—C(5)—C(10)	110.9 (4)	C(16)—C(17)—C(19)	109.1 (5)
C(6)—C(5)—C(10)	111.8 (4)	O(3)—C(17)—C(19)	108.4 (5)
C(6)—C(7)—C(8)	109.1 (4)	C(19)—C(20)—C(21)	177.7 (7)
C(7)—C(8)—C(9)	111.2 (4)	C(11)—C(22)—C(23)	120.5 (4)
C(8)—C(9)—C(11)	115.5 (4)	C(22)—C(23)—C(24)	123.2 (5)
C(10)—C(9)—C(11)	123.0 (5)	N(1)—C(25)—C(24)	121.5 (5)
C(1)—C(10)—C(9)	123.2 (5)	N(1)—C(25)—C(26)	122.3 (5)
C(9)—C(11)—C(22)	110.6 (4)	C(22)—C(27)—C(26)	121.2 (5)
C(9)—C(11)—C(12)	114.1 (4)	O(1)—C(31)—C(30)	105.9 (5)

C(10)—C(1)—C(2)—C(3)	56.8 (6)
C(1)—C(2)—C(3)—C(4)	−57.1 (6)
C(2)—C(3)—C(4)—C(5)	55.2 (6)
C(3)—C(4)—C(5)—C(10)	−50.7 (6)
C(4)—C(5)—C(10)—C(1)	50.0 (6)
C(5)—C(10)—C(1)—C(2)	−54.2 (6)
C(13)—C(12)—C(11)—C(9)	44.2 (6)
C(12)—C(11)—C(9)—C(8)	−42.0 (6)
C(11)—C(9)—C(8)—C(14)	49.1 (6)
C(9)—C(8)—C(14)—C(13)	−61.2 (6)
C(8)—C(14)—C(13)—C(12)	63.6 (5)
C(14)—C(13)—C(12)—C(11)	−52.7 (6)
C(8)—C(9)—C(10)—C(5)	−14.0 (8)
C(9)—C(10)—C(5)—C(6)	− 3.0 (7)
C(10)—C(5)—C(6)—C(7)	42.6 (6)
C(5)—C(6)—C(7)—C(8)	−66.8 (6)
C(6)—C(7)—C(8)—C(9)	48.9 (6)
C(7)—C(8)—C(9)—C(10)	−10.1 (7)
C(16)—C(17)—C(13)—C(14)	42.0 (5)
C(17)—C(13)—C(14)—C(15)	−44.5 (5)
C(13)—C(14)—C(15)—C(16)	30.3 (6)
C(14)—C(15)—C(16)—C(17)	−3.7 (6)
C(15)—C(16)—C(17)—C(13)	−23.8 (6)

Ring *A*
ΔC_s[C(1)] = 5.08
ΔC_s[C(2)] = 0.73
ΔC_s[C(3)] = 4.4
ΔC_2[C(1)—C(2)] = 4.2
ΔC_2[C(2)—C(3)] = 2.7
ΔC_2[C(3)—C(4)] = 6.6

Ring *B*
ΔC_2[C(6)—C(7)] = 6.7

Ring *C*
ΔC_s[C(9)] = 12.3
ΔC_s[C(11)] = 2.8
ΔC_s[C(12)] = 15.1
ΔC_2[C(8)—C(9)] = 19.3
ΔC_2[C(9)—C(11)] = 6.9
ΔC_2[C(11)—C(12)] = 12.7

Ring *D*
ΔC_2[C(13)] = 4.9

A $\Delta\rho$ map showed the positions of all H atoms. H atoms were included in the refinement at calculated positions riding on their bonded atoms with fixed isotropic displacement parameters. *SHELXTL-Plus* (Sheldrick, 1990) was used for data processing, structure solution and refinement. *PARST* (Nardelli, 1983) was used for the final interpretation of molecular geometry and crystal packing. All calculations were performed on a VAX 3100 workstation.

Lists of structure factors, anisotropic displacement parameters and H-atom coordinates have been deposited with the IUCr (Reference: LI1089). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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(3*S*,3a*R*,4*R*,7*S*,7a*S*,*SS*)-3-Ethoxy-3a,4,7,7a-tetrahydro-4,7-methano-7a-*p*-tolysulfinyl-1(3*H*)-isobenzofuranone

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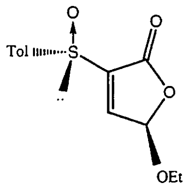
Abstract

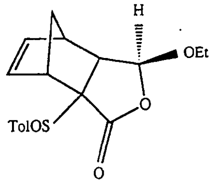
The molecular structure of the title compound, $C_{18}H_{20}O_4S$, determined from the X-ray data confirms the structure previously assigned on the basis of chemical and spectroscopic evidence. The S atom has the usual distorted tetrahedral configuration. The molecular skeleton of the molecule comprises a system of three five-membered rings (*A*, *B* and *C*). The *A* and *B* rings are *cis* fused; all three five-membered rings adopt envelope conformations. The crystal structure is stabilized entirely by van der Waals forces and three C—H···O hydrogen-bond interactions.

Comment

The thermal and catalysed Diels–Alder reactions of (5*S*,*SS*)-5-ethoxy-3-*p*-tolysulfinyl-2(5*H*)-furanone (1) with cyclopentadiene in dichloromethane afford the adduct (2) as the principal product.



(1)



(2)

The empirical formula of (2), $C_{18}H_{20}O_4S$, was established by high-resolution mass spectrometry and the functional groups present in the molecule were characterized by IR and NMR spectroscopy (Carretero, García, Ruano, Lorente & Yuste, 1993).

The *A* and *B* rings are *cis* fused at the C(3*A*)—C(7*A*) bond and the *B* and *C* rings are fused at C(4)—C(8)—C(7). The *A*, *B* and *C* five-membered rings are in envelope conformations. The Δ and ϕ values (Altona, Geise & Romers, 1968) of these rings, *A*, *B* and *C*, are 32.2 (4) and 4.7 (4)°, 40.3 (4) and 62.6 (4)° and 33.3 (5) and 52.1 (5)°, respectively. The packing in the crystal is entirely due to van der Waals forces and three C—H···O hydrogen-bond interactions of < 3.5 Å: C(4)···O(1) 3.410 (6), C(5)···O(4)(1–*x*, –0.5 + *y*, 1.5–*z*) 3.487 (6) and C(13)···O(4)(–*x*, –0.5 + *y*, 1.5–*z*) 3.338 (5) Å.

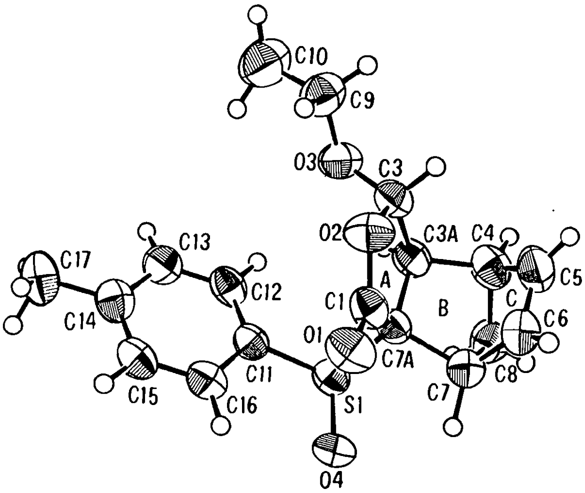


Fig. 1. The molecular structure of the title compound with numbering. The displacement ellipsoids are drawn at the 50% probability level.

Experimental

A solution of (1) (0.2 mmol, 1 eq.) in CH_2Cl_2 (2.5 ml) was added to a cooled (273 K) stirred solution of $ZnBr_2$ (0.24 mmol, 1.2 eq.) in 2.5 ml of CH_2Cl_2. After stirring for 15 min, cyclopentadiene (1.2 mmol, 6 eq.) was added and the mixture was stirred for a further hour. Aqueous $NaHCO_3$ (10%, 10 ml) was added to the mixture. The organic phase

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