

C9	-0.1515 (2)	-0.35676 (9)	-0.2497 (3)	0.0559 (5)
C10	-0.1160 (2)	-0.28055 (8)	-0.0493 (3)	0.0523 (5)
C11	-0.3396 (2)	-0.27130 (9)	-0.2650 (3)	0.0556 (5)
C12	-0.2925 (3)	-0.29833 (10)	-0.4234 (3)	0.0661 (7)
C13	-0.1560 (3)	-0.31685 (10)	-0.3962 (3)	0.0669 (7)
C14	-0.1221 (3)	-0.24143 (9)	0.1969 (3)	0.0615 (6)
C15	-0.2575 (3)	-0.22304 (9)	-0.2267 (3)	0.0619 (6)
C16	-0.0720 (3)	-0.26845 (12)	-0.3541 (4)	0.0743 (8)
C17	-0.7078 (4)	-0.36671 (13)	-0.2000 (4)	0.0858 (9)

Table 2. Selected geometric parameters (Å, °)

S4'—C1'	1.811 (2)	N3—C2	1.359 (3)
S4'—C4'	1.830 (2)	N3—C4	1.396 (2)
O2—C2	1.233 (2)	C1'—C2'	1.530 (3)
O3'—C3'	1.424 (2)	C2'—C3'	1.517 (3)
O4—C4	1.223 (2)	C3'—C4'	1.517 (2)
O5'—C5'	1.434 (3)	C4'—C5'	1.519 (3)
O7—C17	1.397 (4)	C4—C5	1.456 (3)
N1—C2	1.370 (3)	C5—C6	1.346 (3)
N1—C6	1.378 (2)	C5—C7	1.525 (2)
N1—C1'	1.500 (2)		
C1'—S4'—C4'	95.21 (8)	O3'—C3'—C4'	106.77 (14)
C2—N1—C6	120.5 (2)	C2'—C3'—C4'	106.7 (2)
C2—N1—C1'	115.19 (14)	C3'—C4'—C5'	114.4 (2)
C6—N1—C1'	124.09 (14)	C3'—C4'—S4'	104.94 (12)
C2—N3—C4	127.4 (2)	C5'—C4'—S4'	109.56 (14)
N1—C1'—C2'	112.3 (2)	O4—C4—N3	118.5 (2)
N1—C1'—S4'	113.65 (12)	O4—C4—C5	126.9 (2)
C2'—C1'—S4'	105.88 (13)	N3—C4—C5	114.7 (2)
C3'—C2'—C1'	107.62 (14)	O5'—C5'—C4'	111.0 (2)
O2—C2—N3	122.8 (2)	C6—C5—C4	117.3 (2)
O2—C2—N1	121.7 (2)	C6—C5—C7	122.6 (2)
N3—C2—N1	115.5 (2)	C4—C5—C7	120.1 (2)
O3'—C3'—C2'	111.6 (2)	C5—C6—N1	124.6 (2)
C2—N1—C1'—C2'	-80.6 (2)		
C6—N1—C1'—C2'	94.0 (2)		
C2—N1—C1'—S4'	159.24 (14)		
C6—N1—C1'—S4'	-26.2 (2)		
C4'—S4'—C1'—C2'	-8.74 (14)		
S4'—C1'—C2'—C3'	33.1 (2)		
C1'—C2'—C3'—C4'	-47.8 (2)		
C2'—C3'—C4'—S4'	39.2 (2)		
C1'—S4'—C4'—C3'	-17.45 (13)		
C3'—C4'—C5'—O5'	-65.5 (2)		
S4'—C4'—C5'—O5'	176.94 (12)		

Image-plate scans were recorded covering 180° of rotation in 3° frames about one axis, with crystal-detector distance 78 mm and exposure time 10 min frame⁻¹. The resulting data contains ca 86% of the theoretically accessible independent reflections. Coordinates and anisotropic displacement parameters were refined for non-H atoms. H atoms, except those of the methanol methyl group, were located from a difference map and were refined with isotropic displacement parameters. The methanol methyl H atoms were placed in calculated positions and only their isotropic displacement parameters were refined.

Data collection: *R-Axis II Software* (Rigaku Corporation, 1994). Cell refinement: *R-Axis II Software*. Data reduction: *TEXSAN* (Molecular Structure Corporation, 1993). Program(s) used to solve structure: *TEXSAN*. Program(s) used to refine structure: *SHELXL93* (Sheldrick, 1993). Molecular graphics: *ORTEPII* (Johnson, 1976). Software used to prepare material for publication: *SHELXL93*.

We thank the EPSRC and the University of Birmingham for funds to purchase the X-ray diffractometer and the British Council (Sino-British Friendship Scholarship to MS).

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and complete geometry have been deposited with the IUCr (Reference: HA1160). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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(2a*S*,3*S*,6*S*,7*S*,7*bR*)-7-[(Dimethylphenyl)silyl]-2-oxo-6-[(1*R*,2*S*)-2-phenylcyclohexyloxy]-2a,3,6,7,7a,7b-hexahydro-2*H*-1,4,5-trioxa-4a-azacyclopenta[*cd*]indene-3-carboxylic Acid 1-Methylethyl Ester

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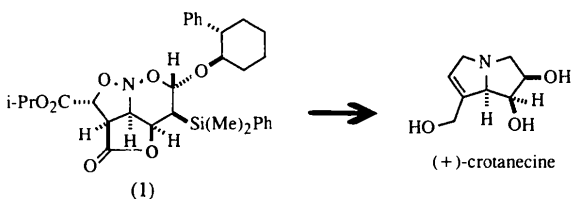
Abstract

The structure of the title compound, C₃₁H₃₉NO₇Si, was determined and found to be a fused tricyclic nitroso acetal. Remarkable features include a twist-boat

conformation of the tetrahydro-1,2-oxazine ring and a highly pyramidalized N atom [$\Sigma(\text{angles}) = 310.6(6)^\circ$]. Three of the contiguous stereocenters in the nitroso acetal are of the same correct relative and absolute configuration as is found in (+)-crotanecine.

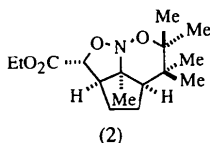
Comment

Nitroso acetals are rather rare and delicate molecules and considerable synthetic effort has been devoted to their preparation in recent years (Denmark & Thorarensen 1996; Rudchenko, 1993). There is only a handful of X-ray crystallographic structure determinations of this class of compounds in the literature. In view of their unique O—N—O linkage and their synthetic utility, the details of molecular structure are valuable. The title compound, (1), was prepared as a part of our program of alkaloid synthesis, in this case specifically aimed towards the pyrrolizidine base (+)-crotanecine (Culvenor & Smith, 1972). The compound was synthesized by the use of our tandem nitroalkene [4 + 2]/[3 + 2] cycloaddition in an analogous fashion to our recently reported synthesis of (–)-rosmarinecine (Denmark, Thorarensen & Middleton, 1995). The chiral auxiliary used in the sequence herein was (–)-(1*R*,2*S*)-2-phenylcyclohexanol (Denmark, Schnute & Senanayake, 1993).



The primary structural information gleaned from the X-ray analysis is the verification of the relative (and absolute) configuration of the six contiguous stereogenic centers, C2, C2a, C7b, C4a, C5 and C6. These configurations are uniquely established by an *exo*-mode [4 + 2] cycloaddition followed by an *endo*-mode [3 + 2] cycloaddition. Furthermore, the *cis* disposition of HC5, HC4a and HC7b are the same as found in the pyrrolizidine base, crotanecine. Finally, the relative configuration of C6 and C24 (known to be 24*R*) ensures that the absolute configurations at the critical stereocenters correspond to the natural configuration of (+)-crotanecine.

Other structural details of note are revealed by comparison with a simpler analog of a similar ring structure, (2), which has also been prepared and crystallographically defined (Denmark, Moon & Senanayake, 1990).



In both of these structures the tetrahydro-1,2-oxazine ring exists in a twist-boat conformation. Moreover, the N—O bond in the 1,2-oxazine is 0.09 Å longer than the N—O bond in the isoxazolidine. Also noteworthy is the extreme pyramidalization of the N atom [$\Sigma(\text{angles}) = 310.6(6)^\circ$].

A final structural attribute of (1) which critically differentiates its reactivity from that of (2) is the contraction of the five-membered lactone ring in (1) compared to the carbocycle in (2). The O—C4a, O—C3 and C3—C2a bonds are 0.08, 0.18 and 0.03 Å, respectively, shorter than the corresponding C—C bonds in (2). Taken together with the *sp*² hybridization of C3, these changes increase the strain in the ring and explain the greater difficulty in subsequent manipulations of (1) compared with (2).

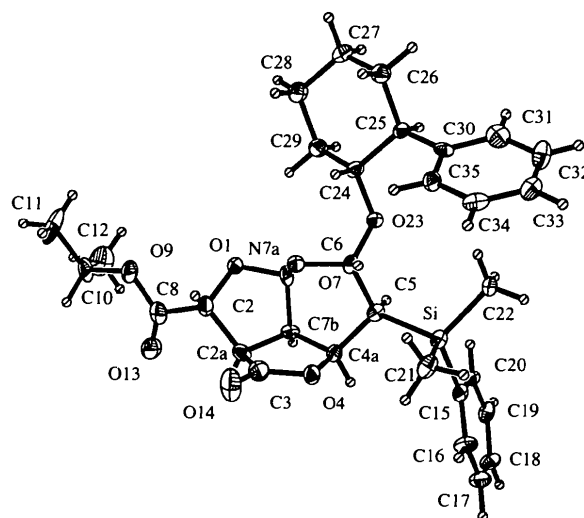


Fig. 1. ORTEP (Johnson, 1971) plot showing 35% probability displacement ellipsoids for non-H atoms. H atoms are drawn as circles of arbitrary radius.

Experimental

The preparation of compound (1) will be described in full elsewhere. Single crystals (m.p. 474–476 K) were obtained from methanol.

Crystal data

C₃₁H₃₉NO₇Si
M_r = 565.72
 Orthorhombic
*P*2₁2₁2₁
a = 9.9730 (10) Å
b = 10.7410 (10) Å
c = 27.527 (3) Å
V = 2948.7 (5) Å³
Z = 4
D_x = 1.274 Mg m^{−3}
D_m not measured

Mo *K*α radiation
 λ = 0.71073 Å
 Cell parameters from 270 reflections
 θ = 1.48–23.00°
 μ = 0.127 mm^{−1}
T = 198 (2) K
 Hollow rod
 0.40 × 0.14 × 0.08 mm
 Colorless

Data collection

Siemens three-circle platform CCD diffractometer	$R_{\text{int}} = 0.1862$
ω - θ scan profiles	$\theta_{\text{max}} = 23.00^\circ$
Absorption correction: none	$h = -13 \rightarrow 12$
12795 measured reflections	$k = -7 \rightarrow 13$
4088 independent reflections	$l = -36 \rightarrow 34$
2265 observed reflections [$I > 2\sigma(I)$]	24 standard reflections monitored every 63 frames
	frequency: 390 min
	intensity decay: none

Refinement

Refinement on F^2	Extinction correction: <i>SHELXL93</i> (Sheldrick, 1993)
$R[F^2 > 2\sigma(F^2)] = 0.0905$	Extinction coefficient: 0.0020 (4)
$wR(F^2) = 0.1653$	Atomic scattering factors from <i>International Tables for Crystallography</i> (1992), Vol. C, Tables 4.2.6.8 and 6.1.1.4)
$S = 1.116$	Absolute configuration: Flack (1983)
4008 reflections	Flack parameter = 0.76 (41)
366 parameters	
H-atom parameters not refined	
$w = 1/[\sigma^2(F_o^2) + 5.5747P]$	
where $P = (F_o^2 + 2F_c^2)/3$	
$(\Delta/\sigma)_{\text{max}} = 0.001$	
$\Delta\rho_{\text{max}} = 0.290 \text{ e } \text{\AA}^{-3}$	
$\Delta\rho_{\text{min}} = -0.282 \text{ e } \text{\AA}^{-3}$	

Table 1. Fractional atomic coordinates and equivalent isotropic displacement parameters (\AA^2)
$$U_{\text{eq}} = (1/3)\sum_i\sum_j U_{ij}a_i^*a_j^* \mathbf{a}_i \cdot \mathbf{a}_j.$$

	<i>x</i>	<i>y</i>	<i>z</i>	U_{eq}
Si	0.2709 (2)	0.9354 (2)	0.85474 (9)	0.0290 (7)
O1	0.5023 (6)	0.4472 (5)	0.9067 (2)	0.034 (2)
C2	0.5536 (9)	0.4917 (8)	0.9532 (3)	0.034 (3)
C2a	0.5924 (9)	0.6275 (8)	0.9436 (3)	0.033 (3)
C3	0.5086 (11)	0.7185 (9)	0.9714 (4)	0.044 (3)
O4	0.4542 (6)	0.8062 (5)	0.9421 (2)	0.034 (2)
C4a	0.4798 (9)	0.7764 (8)	0.8911 (3)	0.027 (2)
C5	0.3502 (8)	0.7767 (7)	0.8617 (3)	0.025 (2)
C6	0.2575 (9)	0.6731 (7)	0.8807 (3)	0.026 (2)
N7a	0.4546 (7)	0.5490 (7)	0.8801 (2)	0.033 (2)
O7	0.3321 (5)	0.5825 (5)	0.9076 (2)	0.030 (2)
C7b	0.5517 (8)	0.6498 (7)	0.8911 (3)	0.025 (2)
C8	0.6732 (12)	0.4069 (10)	0.9646 (3)	0.037 (3)
O9	0.6257 (6)	0.2938 (6)	0.9744 (2)	0.044 (2)
C10	0.7248 (11)	0.1953 (9)	0.9844 (4)	0.049 (3)
C11	0.6429 (11)	0.0902 (10)	1.0072 (4)	0.087 (4)
C12	0.7921 (11)	0.1559 (9)	0.9394 (4)	0.073 (4)
O13	0.7883 (7)	0.4377 (6)	0.9638 (2)	0.049 (2)
O14	0.4923 (9)	0.7241 (7)	1.0144 (2)	0.068 (3)
C15	0.4049 (8)	1.0380 (8)	0.8276 (3)	0.025 (2)
C16	0.4583 (9)	1.1422 (8)	0.8498 (3)	0.038 (3)
C17	0.5575 (10)	1.2125 (9)	0.8277 (3)	0.042 (3)
C18	0.6030 (9)	1.1808 (8)	0.7823 (3)	0.035 (3)
C19	0.5520 (9)	1.0803 (8)	0.7581 (3)	0.035 (2)
C20	0.4539 (9)	1.0104 (7)	0.7808 (3)	0.030 (2)
C21	0.2137 (9)	0.9946 (8)	0.9144 (3)	0.042 (3)
C22	0.1331 (8)	0.9228 (8)	0.8100 (3)	0.035 (2)
O23	0.1924 (5)	0.6218 (5)	0.8407 (2)	0.028 (2)
C24	0.1025 (8)	0.5206 (7)	0.8521 (3)	0.028 (2)
C25	-0.0262 (8)	0.5350 (7)	0.8229 (3)	0.025 (2)
C26	-0.1200 (9)	0.4257 (8)	0.8324 (3)	0.037 (3)
C27	-0.0527 (10)	0.3005 (8)	0.8212 (3)	0.038 (3)
C28	0.0771 (9)	0.2856 (8)	0.8498 (4)	0.041 (3)
C29	0.1709 (9)	0.3970 (7)	0.8410 (3)	0.035 (2)
C30	-0.0974 (8)	0.6573 (8)	0.8312 (3)	0.026 (2)
C31	-0.1685 (10)	0.7125 (10)	0.7935 (3)	0.046 (3)

C32	-0.2320 (10)	0.8268 (9)	0.7986 (4)	0.046 (3)
C33	-0.2267 (9)	0.8859 (8)	0.8422 (4)	0.039 (3)
C34	-0.1624 (9)	0.8324 (9)	0.8808 (4)	0.040 (3)
C35	-0.0988 (9)	0.7175 (9)	0.8755 (3)	0.032 (3)

Table 2. Selected geometric parameters (\AA , $^\circ$)

O1—N7a	1.399 (8)	C3—O4	1.355 (11)
O1—C2	1.460 (9)	O4—C4a	1.460 (9)
C2a—C3	1.497 (12)		
O1—N7a—O7	101.7 (5)	O7—N7a—C7b	104.9 (6)
O1—N7a—C7b	104.0 (6)		
O1—N7a—O7—C6	-170.5 (6)	O1—N7a—C7b—C4a	-147.2 (6)
O1—N7a—C7b—C2a	-34.7 (8)		

The data crystal was mounted using oil (Paratone-N, Exxon) onto a thin glass fiber. A lower 2θ limit of 46° was imposed owing to the weak reflections of the data crystal. Intensity data were reduced by three-dimensional profile analysis and corrections were made for Lorentz effects and extinction. 80 data peaks with very negative F_o^2 were suppressed.

Methyl H-atom positions R —CH₃ were optimized by rotation about R —C bonds with idealized C—H, R —H and H—H distances. The remaining H atoms were included as fixed idealized contributors. H-atom U values were assigned as $1.2U_{\text{eq}}$ of adjacent non-H atom. The final difference map had no significant features. A final analysis of variance between observed and calculated structure factors showed a slight dependence on amplitude.

Data collection: *SMART* (Siemens, 1994). Cell refinement: *SAINT* (Siemens, 1994). Data reduction: *SAINT*. Program(s) used to solve structure: *SHELXS86* (Sheldrick, 1990). Program(s) used to refine structure: *SHELXL93* (Sheldrick, 1993). Molecular graphics: *SHELXTL-Plus* (Siemens, 1994) and *ORTEPII* (Johnson, 1971). Software used to prepare material for publication: *CIFTAB SHELXL93*.

The authors are grateful to the National Institutes of Health (GM-30938) for generous financial support. AT thanks the University of Illinois for a Graduate Fellowship. We also thank Dr Scott R. Wilson for technical assistance and advice.

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and complete geometry have been deposited with the IUCr (Reference: SK1015). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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***rel*-(1*R*,6*S*,7*S*,8*R*,9*S*)-9-Methyl-8-phenyl-6-[(1*S*,2*R*)-(2-phenylcyclohexyl)oxy]-4-aza-3,5-dioxatricyclo[5.2.1.0^{4,9}]decane**

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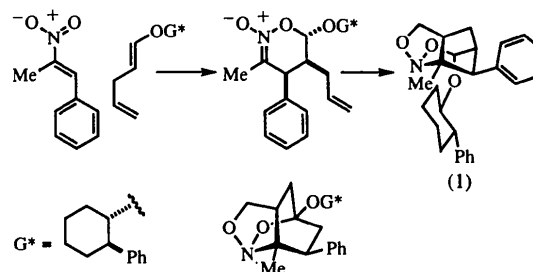
(Received 1 March 1996; accepted 20 May 1996)

Abstract

The structure of the title compound, C₂₆H₃₁NO₃, was determined by X-ray crystallography. It was found to be a unique bridged tricyclic nitroso acetal. Notable features include a chair conformation of the tetrahydro-1,2-oxazine ring and a highly pyramidalized N atom [$\Sigma_{\text{angles}} = 314.2(6)^\circ$]. The configurations of the five contiguous stereogenic centers in the nitroso acetal establish that the tandem cycloaddition sequence proceeded via an *exo*-[4 + 2]/*endo*-[3 + 2] pathway.

Comment

Although nitroso acetals are rather uncommon and labile molecules, their preparation and potential for organic synthesis has attracted considerable attention in recent years (Denmark & Thorarensen 1996; Rudchenko, 1993). Of the known nitroso acetals, only a small subset has been characterized by X-ray crystallography. The details of their molecular structure are valuable because of the unique O—N—O linkage, the diversity of the skeletons in which they have been made and their synthetic utility. The title compound, (1), was prepared as a part of our methodological program on the scope and limitations of our tandem nitroalkene [4 + 2]/[3 + 2] cycloaddition process. We have documented four different modes of inter[4 + 2]/intra[3 + 2] reactions. Compound (1) represents the first reported example of a bridged-mode tandem cycloaddition that forms an imbedded cyclopentane skeleton. An analogous process leading to an imbedded cyclohexane skeleton was reported recently (Denmark, Stolle, Dixon & Guagnano, 1995). The chiral auxiliary used in this



sequence was again (\pm)-(1*R*,2*S*)-2-phenylcyclohexanol (Denmark, Schnute & Senanayake, 1993).

The primary structural information provided by the X-ray analysis is the verification of the tricyclo[5.2.1.0^{4,9}] core structure. The relative configurations of the five contiguous stereogenic centers, C3, C1, C6, C5, and C7, are singularly established by an *exo*-mode [4 + 2] cycloaddition followed by an *endo*-mode [3 + 2] cycloaddition. Furthermore, the existence of a five- rather than a six-membered carbocycle confirms the regiochemical preference in the dipolar cycloaddition expected on the basis of tether length and strain.

Other structural details of note are revealed by comparison of (1) with a related [4.3.1.0^{3,7}] bridged nitroso acetal, (2), which has also been prepared and crystallographically defined (Denmark, Stolle, Dixon & Guagnano, 1995). The boat conformation of the tetrahydro-1,2-oxazine ring is required by the core structure of (2). However, in (1), a chair conformation is found, presumably to allow for anomeric stabilization involving the axially oriented auxiliary via the C7—O3 bond. Furthermore, in (2) the N—O bond in the 1,2-oxazine is 0.051 Å longer than the N—O bond in the isoxazolidine while in compound (1), the N—O bond in the 1,2-oxazine is 0.102 Å longer than the corresponding N—O bond in the isoxazolidine. As in all nitroso acetals,

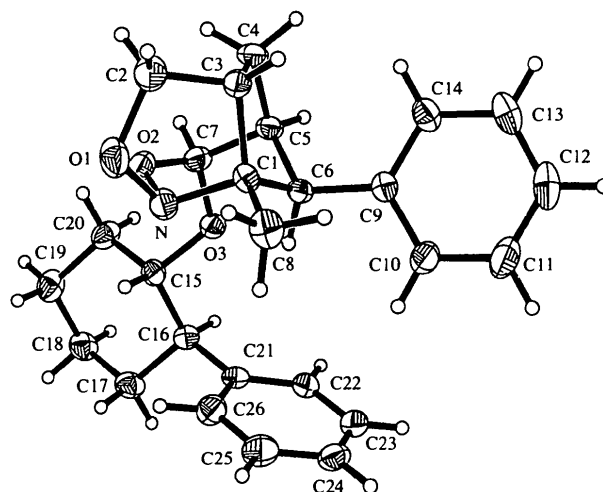


Fig. 1. ORTEP (Johnson, 1971) plot showing 35% probability ellipsoids for non-H atoms and H atoms as circles of arbitrary size.