

NARDELLI, M. (1983). *Comput. Chem.* **7**, 95–98.
 NARDELLI, M. & MANGIA, A. (1984). *Ann. Chim. (Rome)*, **74**, 163–174.
 PARSONS, M. E., OWEN, D. A., GANELLIN, C. R. & DURANT, G. J. (1977). *Agents Actions*, **7**, 31–37.
 SCHOMAKER, V. & TRUEBLOOD, K. N. (1968). *Acta Cryst.* **B24**, 63–76.
 SHELDRIK, G. M. (1976). *SHELX76*. Program for crystal structure determination. Univ. of Cambridge, England.
 TRUEBLOOD, K. N. (1984). *THMV*. Univ. of California, Los Angeles.
 UGOZZOLI, F. (1983). *ABSORB*. Program for Walker & Stuart's Absorption Correction. Univ. of Parma, Italy.

VITALI, T., BERTACCINI, G. & CORUZZI, G. (1978). *Pharmacol. Res. Commun.* **10**, 747–757.
 VITALI, T., BERTACCINI, G., IMPICCIATORE, M. & PLAZZI, V. (1972). *Farmaco Ed. Sci.* **27**, 680–682.
 VITALI, T., BERTACCINI, G., IMPICCIATORE, M. & PLAZZI, V. (1979). *Farmaco Ed. Sci.* **32**, 41–51.
 VITALI, T., IMPICCIATORE, M., PLAZZI, P. V., BORDI, F. & MORINI, G. (1986). *Farmaco Ed. Sci.* **41**, 483–498.
 VITALI, T., IMPICCIATORE, M., PLAZZI, V., BORDI, F. & VITTO, M. (1984). *Farmaco Ed. Sci.* **39**, 70–80.
 WALKER, N. & STUART, D. (1983). *Acta Cryst.* **A39**, 158–166.
 WALKINSHAW, M. D. (1986). *Acta Cryst.* **C42**, 246–249.
 ZACHARIASEN, W. H. (1963). *Acta Cryst.* **16**, 1139–1144.

Acta Cryst. (1987). **C43**, 514–517

Structures of 3-Cyano-6-nitro-1,2,3,4,5,10-hexahydro-6-nitronaphth[2,3-*e*][1,2]oxazines. 1

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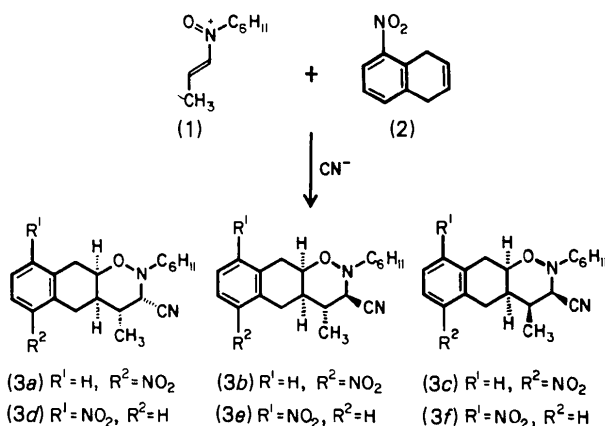
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Abstract. 2-Cyclohexyl-4 α -methyl-3,4,4 α ,5,10,10 α -hexahydro-6-nitronaphth[2,3-*e*][1,2]oxazine-3 β -carbonitrile, $C_{20}H_{25}N_3O_3$, $M_r = 355.43$, monoclinic, $P2_1/n$, $a = 13.375$ (9), $b = 11.601$ (8), $c = 12.725$ (8) Å, $\beta = 109.49$ (6)°, $V = 1861.32$ Å³, $Z = 4$, $D_x = 1.268$ g cm⁻³, $\lambda(\text{Cu } K\alpha) = 1.5418$ Å, $\mu(\text{Cu } K\alpha) = 6.15$ cm⁻¹, $F(000) = 760$, room temperature, final $R = 0.052$, $wR = 0.058$ for 2742 unique observed [$I > 0$] reflections. In this nitro-substituted derivative the tetrahydrooxazine ring is in a distorted chair conformation with exceptionally large endocyclic torsion angles about the C(1A)—O(1) and O(1)—N(2) bonds [71.4 (2) and -76.6 (2)°, respectively]. Both the methyl and the cyano substituents are in axial positions.

Introduction. This investigation forms part of a study of the cycloaddition reactions of the *N*-cyclohexyl-*N*-propenylnitrosonium ion (1) (Kempe, Das Gupta, Blatt, Gyax, Felix & Eschenmoser, 1972) with 5-substituted 1,4-dihydronaphthalenes (Holzapfel, Koekemoer & Van Dyk, 1985). The reaction of 5-nitro-1,4-dihydronaphthalene (2) with (1) furnished four isomeric iminium ions which on treatment with potassium cyanide yielded the corresponding cyanide adducts (3*a*–3*f*). The stereochemistry of the *cis*-fused *B/C* ring system of these hexahydronaphthoxazines (assignment based on an analysis of the ¹H NMR spectra) can be described as 3 α ,4 α , 3 β ,4 α and 3 β ,4 β with respect to the cyano and methyl substituents. The 3 α ,4 α - and 3 β ,4 α -stereoisomers with the same regiochemistry are chemically interconvertible (Van Dyk, 1986). In order to establish the regioselectivity of the cycloaddition

reaction the unambiguous structure determination of at least one isomer with a 4 α -methyl and one with a 4 β -methyl substituent was required.



In addition, the stereochemistry and conformation deduced on the basis of ¹H NMR implied that both the cyano and methyl substituents in the 3 β ,4 α -isomers are in sterically crowded axial positions. This result can be compared with the ¹H NMR-based conclusion of Riediker & Graf (1979) that 2-cyclohexyl-3 β -cyano-4 α -mesyloxymethyl-4 α ,8 α -perhydro-1,2-benzoxazine has a preferred conformation in which the β -cyano and α -mesyloxymethyl substituents are in axial positions, a finding that was interpreted in terms of a generalized anomeric effect operating in the α -cyano-hydroxylamine-ether structural unit.

An interest in the regiochemistry of the cycloaddition reaction as well as the stereochemistry and conformation of the oxazine rings of the $3\beta,4\alpha$ -stereoisomers led to an X-ray investigation of the title compound (3b). It was also the only cyano adduct from the nitro-substituted series which yielded suitable crystals.

Experimental. Reaction of (1) (prepared *in situ*) with (2) in a 2:1 mixture of liquid SO_2 and dichloroethane at 263 K and work-up with potassium cyanide according to the procedure developed by Van Dyk (1986) yielded a mixture of the six cyanide adducts (3a–3f) from which the title compound (3b) was isolated by medium pressure chromatography on silica. Crystallization from dichloromethane–hexane yielded pale yellow prisms, m.p. 447–450 K. Analysis: calculated for $\text{C}_{20}\text{H}_{25}\text{N}_3\text{O}_3$: C 67.6, H 7.1, N 11.8%; found: C 67.4, H 7.2, N 11.5%. ^1H NMR (500 MHz): 1.27 (*d*, $J = 7.1$ Hz, 3 H), 1.62 (*m*, $J = 10.8, 5.2, 3.7$ and 3.7 Hz, 1 H), 1.13–2.15 (*m*, 10 H), 2.21 (*m*, $J = 7.1, 3.7$ and 3.3 Hz, 1 H), 2.81 (*m*, 1 H), 3.09 (*dd*, $J = 17.2$ and 5.2 Hz, 1 H), 3.02 (*dd*, $J = 17.8$ and 2.9 Hz, 1 H), 3.16 (*dd*, $J = 17.8$ and 7.3 Hz, 1 H), 3.45 (*dd*, $J = 17.2$ and 10.8 Hz, 1 H), 3.70 (*d*, $J = 3.3$ Hz, 1 H), 4.47 (*m*, 1 H), 7.22 (*t*, $J = 7.8$ Hz, 1 H), 7.29 (*d*, $J = 7.7$ Hz, 1 H), 7.66 (*d*, $J = 8.1$ Hz, 1 H).

Crystal dimensions approximately $0.40 \times 0.25 \times 0.25$ mm. Lattice parameters refined using 25 reflections in the range $5 < \theta < 24^\circ$. Philips PW 1100 diffractometer, graphite-monochromated Cu K α radiation. Intensity data collected with $\omega/2\theta$ scan technique ($\theta < 60^\circ$) on 2921 reflections [2742 unique reflections (observed with $I > 0$), $-14 \leq h \leq 14$, $k \leq 12$, $l \leq 14$]. Intensities of three standard reflections showed no decay. The data were corrected for Lorentz and polarization effects; no corrections for absorption or secondary extinction. The structure was solved by direct methods as applied for centrosymmetric space groups in the *EEES* routine of *SHELX76* (Sheldrick, 1976). Scattering factors from *International Tables for X-ray Crystallography* (1974). The structure was refined by a full-matrix least-squares procedure minimizing the function $\sum w(|F_o| - |F_c|)^2$ with $w = [\sigma(F)]^{-2}$. The full-matrix least-squares program *SHELX76* (Sheldrick, 1976) was used. Refinement with non-hydrogen atoms treated anisotropically and hydrogen atoms (located from difference maps) isotropically produced convergence with $R = 0.052$ and $wR = 0.058$. When the refinement was terminated all shift/e.s.d. ratios were less than 0.27. A final difference Fourier synthesis showed $\Delta\rho_{\min} = -0.40$ and $\Delta\rho_{\max} = 0.26 \text{ e } \text{Å}^{-3}$.

Discussion. Table 1 gives the final positional and equivalent isotropic thermal parameters for the non-H

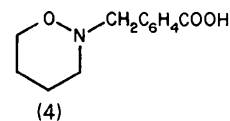
Table 1. Atomic fractional coordinates ($\times 10^4$) and U_{eq} ($\text{Å}^2 \times 10^3$) for the non-H atoms

	<i>x</i>	<i>y</i>	<i>z</i>	U_{eq}^*
O(1)	3532 (1)	1361 (1)	-915 (1)	34 (1)
N(2)	3111 (1)	1549 (1)	-9 (1)	33 (1)
C(3)	3391 (2)	2737 (2)	359 (2)	35 (1)
C(4)	2801 (2)	3569 (2)	-595 (2)	33 (1)
C(4A)	2965 (2)	3233 (2)	-1699 (2)	31 (1)
C(5)	4050 (2)	3617 (2)	-1732 (2)	35 (1)
C(5A)	4226 (1)	3244 (2)	-2791 (2)	32 (1)
C(6)	4862 (2)	3859 (2)	-3268 (2)	36 (1)
C(7)	4977 (2)	3580 (2)	-4277 (2)	42 (1)
C(8)	4450 (2)	2626 (2)	-4834 (2)	43 (1)
C(9)	3835 (2)	1974 (2)	-4378 (2)	39 (1)
C(9A)	3719 (1)	2268 (2)	-3361 (1)	32 (1)
C(10)	3054 (2)	1504 (2)	-2898 (2)	39 (1)
C(1A)	2816 (2)	1938 (2)	-1880 (2)	31 (1)
C(11)	3594 (2)	642 (2)	817 (2)	37 (1)
C(12)	3197 (2)	-526 (2)	300 (2)	48 (1)
C(13)	3600 (2)	-1494 (2)	1153 (2)	54 (1)
C(14)	3285 (2)	-1297 (2)	2177 (2)	58 (2)
C(15)	3677 (3)	-141 (2)	2694 (2)	60 (2)
C(16)	3307 (2)	852 (2)	1864 (2)	51 (1)
C(17)	4553 (2)	2917 (2)	806 (2)	43 (1)
N(18)	5445 (2)	3010 (2)	1177 (2)	65 (1)
C(19)	1626 (2)	3582 (2)	-712 (2)	44 (1)
N(20)	5486 (2)	4846 (2)	-2665 (2)	46 (1)
O(21)	6051 (1)	4705 (2)	-1702 (1)	63 (1)
O(22)	5422 (2)	5757 (2)	-3155 (2)	69 (1)

* U_{eq} is defined as the geometric mean of the diagonal elements of the diagonalized matrix of U_{ij} .

atoms. The atomic numbering scheme and selected bond lengths and angles are shown in Fig. 1.* Fig. 2 shows a stereo drawing of one molecule of the title compound. The endocyclic torsion angles and ring puckering parameters describing the B and C rings are shown in Table 2.

The conformation of the molecule is essentially determined by that of the tetrahydro-1,2-oxazine ring (C ring), which assumes a distorted chair conformation with exceptionally large endocyclic torsion angles about the O(1)–N(2) and C(1A)–O(1) bonds [-76.6 (2) and 71.4 (2) $^\circ$, respectively]. The N substituent (cyclohexyl group) is in an equatorial position while both the 3β -cyano and 4α -methyl substituents are axial. The solid-state conformation of the molecule is practically the same as the preferred conformation in solution as indicated by the vicinal coupling constants (Van Dyk, 1986).



* Lists of structure factors, anisotropic thermal parameters, positional and isotropic thermal parameters for the H atoms and a list of bond lengths and angles (including H atoms) have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 43449 (25 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

The crystal structure of only one other unbridged tetrahydro-1,2-oxazine system, *N*-(*p*-carboxybenzyl)-tetrahydro-1,2-oxazine (4), has been reported (Riddell, Murray-Rust & Murray-Rust, 1974). Here the oxazine ring is also in a chair conformation with a rather large endocyclic torsion angle (67°) about the O(1)–N(2) bond and the *N* substituent in an equatorial position. The authors ascribed the equatorial position of the *N* substituent as well as the large O(1)–N(2) torsion angle to the tendency of hydroxylamine systems to assume conformations in which repulsive lone-pair–lone-pair interactions are minimized (Radom, Hehre & Pople, 1972).

The conformation of (3*b*) with both methyl and cyano substituents in axial positions would appear to be sterically unfavourable. The noticeably larger torsion angles about the O(1)–N(2) and especially C(1A)–O(1) bonds in (3*b*), compared with (4), are probably the result of a flattening of the C(3)–C(4)–C(4A) half of the ring [N(2)–C(3)–C(4)–C(4A) = –51.2 (2) and C(3)–C(4)–C(4A)–C(1A) = 45.5 (2)°] to relieve unfavourable 1,3-diaxial interactions, *e.g.* between the

Table 2. Conformation of the *B* and *C* rings

Endocyclic torsion angles (°)			
<i>B</i> ring			
C(1A)–C(4A)–C(5)–C(5A)	54.6 (2)	C(4A)–C(5)–C(5A)–C(9A)	–27.3 (3)
C(5)–C(5A)–C(9A)–C(10)	4.9 (3)	C(5A)–C(9A)–C(10)–C(1A)	9.3 (3)
C(9A)–C(10)–C(1A)–C(4A)	19.2 (3)	C(10)–C(1A)–C(4A)–C(5)	–50.6 (2)
<i>C</i> ring			
C(1A)–O(1)–N(2)–C(3)	–76.6 (2)	O(1)–N(2)–C(3)–C(4)	65.0 (2)
N(2)–C(3)–C(4)–C(4A)	–51.2 (2)	C(3)–C(4)–C(4A)–C(1A)	45.5 (2)
C(4)–C(4A)–C(1A)–O(1)	–55.5 (2)	C(4A)–C(1A)–O(1)–N(2)	71.4 (2)
Puckering parameters (Cremer & Pople, 1975)			
<i>B</i> ring [C(1A)–C(4A)–C(5)–C(5A)–C(9A)–C(10)]			
$Q = 0.48 \text{ \AA}$	$\phi = 67.2^\circ$	$\theta = 60.7^\circ$	
<i>C</i> ring [O(1)–N(2)–C(3)–C(4)–C(4A)–C(10)]			
$Q = 0.64 \text{ \AA}$	$\phi = 19.5^\circ$	$\theta = 15.1^\circ$	

cyano group and C(5). The N(2)–C(3) bond is marginally shorter [1.464 (2) Å] than the equivalent bond in (4) [1.478 (6) Å] and the N(2)–C(substituent) bonds in both (3*b*) and (4) [1.476 (2) and 1.483 (6) Å, respectively], which is in accord with the operation of an anomeric effect involving a hyperconjugative n_p – σ^* electron delocalization (Wolfe, Whangbo & Mitchell, 1979), stabilizing this sterically unfavourable conformation.

The envelope conformation of the *B* ring is a result of its fusion to both the aromatic *A* ring and the *C* ring (*cis* fusion in the latter case). The fact that the nitro group is turned out of the plane of the benzene ring [C(5A)–C(6)–N(20)–O(21) = 51.5 (3) and C(7)–C(6)–N(20)–O(22) = 52.7 (3)°] is indicative of steric interactions between it and the hydrogens on C(5).

The equatorial cyclohexyl group on N(2) of (3*b*) leans, as in the case of (4), towards O(1) [O(1)–N(2)–C(11) = 105.3 (1) and C(3)–N(2)–C(11) = 116.0 (1)°]. The specific orientation of this group with respect to the oxazine ring [C(12)–C(11)–N(2)–O(1) = –64.8 (2) and C(16)–C(11)–N(2)–C(3) = 56.9 (2)°] is, however, also determined by the axial cyano group. Molecular mechanics calculations (*MM2* one-bond driver calculations) of Jaime & Ōsawa (1983, 1984) for 1,1'-bipiperidines and 1-cyclohexylpiperidines indicate that in systems with no substituents on the positions vicinal to the nitrogen [for example corresponding to C(3) in (3*b*)] the equivalent orientations represent low-energy rotamers. However, with equatorial substituents on these positions these orientations represent high-energy rotamers. Inspection of a Dreiding model shows that with an axial substituent on C(3) this orientation once again represents a low-energy rotamer.

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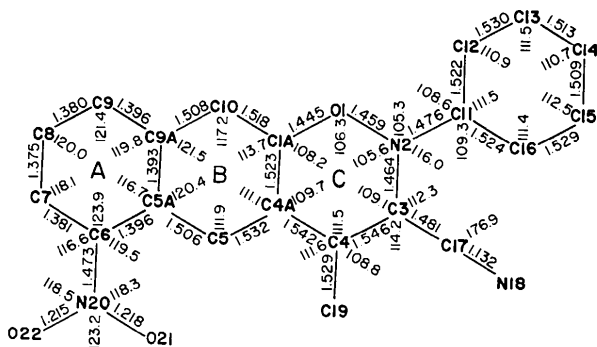


Fig. 1. A schematic drawing of the molecule showing the atom labels and bond lengths (Å) and angles (°). E.s.d.'s for bond lengths are 0.002–0.004 Å, and for angles 0.1–0.2°.

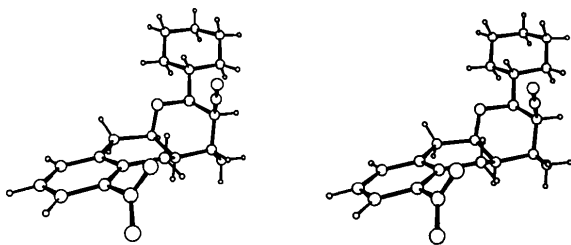


Fig. 2. Stereoview of one molecule of (3*b*).

References

- CREMER, D. & POPLE, J. A. (1975). *J. Am. Chem. Soc.* **97**, 1354–1358.
- HOLZAPFEL, C. W., KOEKEMOER, J. M. & VAN DYK, M. S. (1985). Abstr. Papers 10th International Congress of Heterocyclic Chemistry, Waterloo, Ontario, P1–11.
- International Tables for X-ray Crystallography* (1974). Vol. IV. Birmingham: Kynoch Press. (Present distributor D. Reidel, Dordrecht.)
- JAIME, C. & ŌSAWA, E. (1983). *J. Chem. Soc. Chem. Commun.* pp. 708–709.
- JAIME, C. & ŌSAWA, E. (1984). *J. Chem. Soc. Perkin Trans. 2*, pp. 995–999.
- KEMPE, U. M., DAS GUPTA, T. K., BLATT, K., GYGAX, P., FELIX, D. & ESCHENMOSE, A. (1972). *Helv. Chim. Acta*, **55**, 2187–2198.
- RADOM, L., HEHRE, W. J. & POPLE, J. A. (1972). *J. Am. Chem. Soc.* **94**, 2371–2381.
- RIDDELL, F. G., MURRAY-RUST, P. & MURRAY-RUST, J. (1974). *Tetrahedron*, **30**, 1087–1096.
- RIEDIKER, M. & GRAF, W. (1979). *Helv. Chim. Acta*, **62**, 2053–2061.
- SHELDRICK, G. M. (1976). *SHELX76*. Program for crystal structure determination. Univ. of Cambridge, England.
- VAN DYK, M. S. (1986). PhD Thesis. Rand Afrikaans Univ., South Africa.
- WOLFE, S., WHANGBO, M.-H. & MITCHELL, D. J. (1979). *Carbohydr. Res.* **69**, 1–26.

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Tricyclo[18.2.2.2^{2,5}]hexacos-1(22),2,4,20,23,25-hexaene ([14.0]-*p*-Cyclophane)

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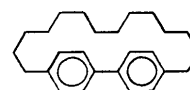
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Abstract. C₂₆H₃₆, *M_r* = 348.6, monoclinic, *C2/c*, *a* = 23.986 (9), *b* = 7.844 (3), *c* = 11.415 (4) Å, β = 92.29 (3)°, *V* = 2146 (1) Å³, *Z* = 4, *D_x* = 1.08 g cm⁻³, Mo *Kα*, λ = 0.71073 Å, μ = 0.56 cm⁻¹, *F*(000) = 768, *T* = 297 K, final *R* = 0.054 for 1162 observed reflections. The title compound is established by an X-ray study to have a twofold axis coinciding with a crystallographic twofold axis, and to be in a different conformation in the crystal from that observed in solution by NMR studies. NMR and molecular mechanics calculations suggest that the solution conformation is a roughly equal mixture of the X-ray structure with a more twisted biphenyl system and a slightly more stable conformation which does not pack as well as the X-ray conformation.

Introduction. The title compound (1) was first prepared by Nakazaki & Yamamoto (1965), who observed that it had proton absorptions in the NMR as far upfield as 0.6, indicating that some of the methylene protons are strongly shielded owing to their position above the benzene ring. We recently found a better route to (1) (to be published elsewhere), and now wish to report the results of an X-ray diffraction study on a crystal of (1) and to compare the conformation observed in the

crystal with what is indicated by NMR and molecular mechanics calculations to be present in solution.



(1)

Experimental. Colorless crystals grown by slow evaporation from pentane at 263 K. Crystal dimensions 0.4 × 0.4 × 0.4 mm. Syntex P2₁ diffractometer. Cell constants from 25 reflections with 13 ≤ 2θ ≤ 24°. Systematic absences: *hkl*, *h* + *k* = 2*n* + 1, *h0l*, *l* = 2*n* + 1. 2θ_{max} = 50°. Range of *hkl*: 0→28, 0→9, -13→13. Scan rate 3–29°. Two check reflections every 98 data points showed 0.4% average decay; no decay or absorption correction. 1162 of 1891 reflections with *I* > 2.5σ(*I*) used in *F*² full-matrix refinement, *R*_{int} = 0.012. Structure solved by *MULTAN80* (Main, Fiske, Hull, Lessinger, Germain, Declercq & Woolfson, 1980) using 224 highest *E* values; all non-H atoms found in first *E* map. Refinement of non-H atoms with isotropic temperature factors gave *R* = 0.10; final refinement (118 parameters) of non-H atoms with anisotropic temperature factors after adding H atoms in calculated positions with isotropic temperature factors

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