

Furazan *N*-Oxides. Part 2.¹ Synthesis and Structure of some Strained Furazan *N*-Oxides

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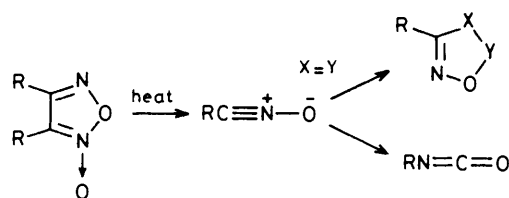
The strained furazan *N*-oxides (5) and (6) have been synthesised from norbornene and dicyclopentadiene by treatment with N_2O_3 , thermal isomerisation of the resulting nitronitroso-adducts to the nitro-oximes [e.g. (9)], and subsequent dehydration at ambient temperature using SO_3 -DMF or $ClSO_3H$ -DMF. Characterisation of the products is based on analytical and spectroscopic evidence by comparison with the known analogues (2) and (3), and in the case of (6) by *X*-ray crystal structure analysis. Compound (6) has *endo*-stereochemistry and is shown by ^{13}C n.m.r. spectroscopy to be, like (2), a mixture of isomers, (6A) and (6B). *X*-Ray crystal structure analysis also showed that (3) has *exo*-stereochemistry and that for both (3) and (6) the O^1-N^2 bond of the oxadiazole is long (1.47 and 1.54 Å).

The thermolysis of 3,4-disubstituted furazan *N*-oxides (furoxans) results in cleavage of the 1,2,5-oxadiazole ring yielding two nitrile oxide fragments,² which may be trapped as their 1,3-dipolar cycloadducts in the presence of a suitable dipolarophile ($X=Y$), or may rearrange to the isomeric isocyanates (Scheme 1). Moreover, furoxans with the heterocycle fused to a second ring [e.g. decamethylenefuroxan (1; $n = 10$)] provide a unique source of both bis-nitrile oxides and di-isocyanates.²

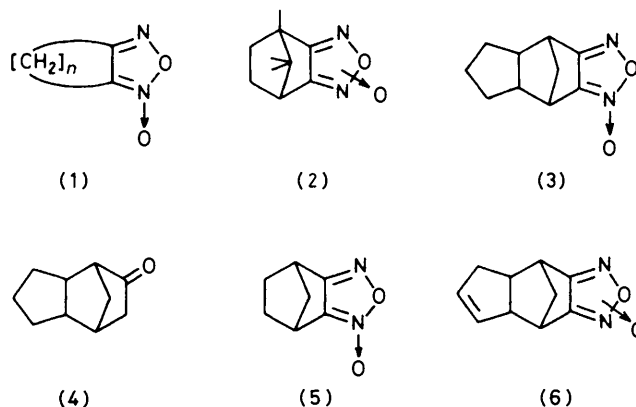
As part of an investigation of the scope of this process we have sought furoxans incorporating the norbornane skeleton. Camphorfuroxan (2) has been known³ for many years, but there are few other examples. The tricyclodecane furoxan (3) has been made from the ketone (4) *via* its isonitroso- and bis-oximino derivatives, but this approach failed⁴ for the parent norbornane furoxan (5). We now report the development of a route to furoxans of the norbornane series from the corresponding alkenes, the method being illustrated by the synthesis of the previously elusive compound (5) and dicyclopentadiene furoxan (6). In addition, the *X*-ray crystal structures of (3) and (6) have been determined in order to establish their stereochemistry, and examine the strain in the heterocyclic ring.

Results and Discussion

The new synthetic approach is based on the reaction sequence: alkene \rightarrow pseudonitrosite \rightarrow 2-nitro-oxime \rightarrow furoxan, used by Klamann⁵ for the preparation of unstrained furoxans [e.g. tetramethylenefuroxan (1; $n = 4$) and 3,4-dimethylfuroxan], but modified to take account of the much greater thermal instability inherent in the furoxans of the norbornane series.⁴ The route is illustrated for norbornene \rightarrow norbornene furoxan in Scheme 2. Passage of dinitrogen trioxide, generated by mixing nitric oxide and air, through a solution of norbornene in diethyl ether-pentane at 0 °C yielded norbornene pseudonitrosite (7), the nitroso-dimer of the first-formed nitronitroso-adduct (8).⁶ Conversion of (7) into the nitro-oxime (9) was achieved by heating under reflux in dioxan-DMF; that the reaction proceeds by initial monomerisation to (8) followed by proton transfer is indicated by the formation and subsequent disappearance of a blue-green coloration.⁵ The conditions of Klamann's procedure for the dehydration of nitro-oximes to furoxans, involving heating in concentrated H_2SO_4 at 125 °C, were considered to be unsuitable for nor-



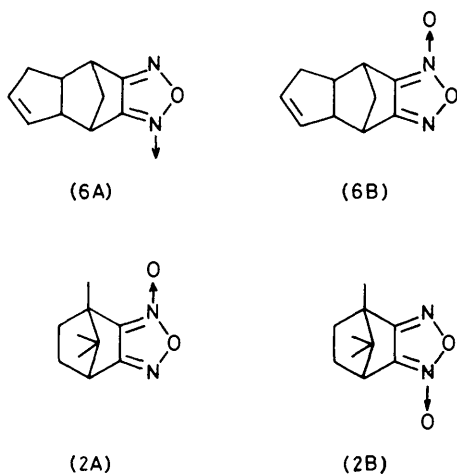
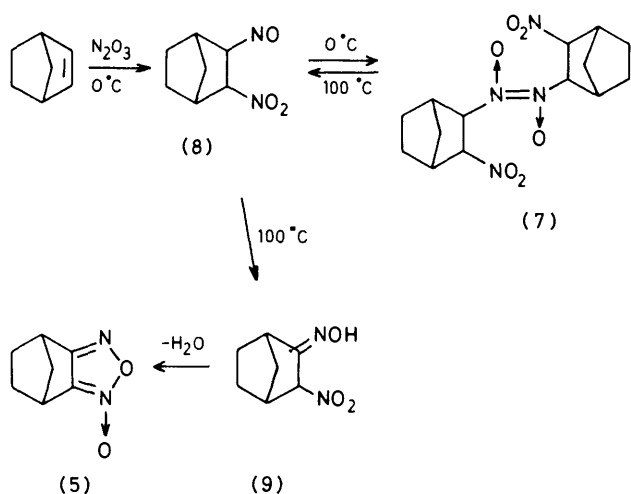
Scheme 1



bornane-type furoxans which fragment at 100 °C.⁴ Instead the conversion was accomplished using SO_3 -DMF (DMF = dimethylformamide) or $ClSO_3H$ -DMF at room temperature, (5) being formed in 72% yield after basic work-up.

The same technique applied to dicyclopentadiene yielded the furoxan (6) *via* the corresponding pseudonitrosites and nitro-oximes⁷ in 28% overall yield. For comparative purposes the camphor-derived furoxan (2) and tricyclodecane furoxan (3) were also prepared by the established literature methods.^{3,4}

The spectroscopic properties of (5) and (6) are similar to those of their known analogues (2) and (3). They show i.r. absorptions characteristic⁴ of strained furoxans at 1 655–1 675 cm^{-1} , significantly shifted from the value of ca. 1 600 cm^{-1} normal for unstrained cases [e.g. (1; $n = 4$)].⁸ Their mass spectra are also typical of this class of heterocycle;^{4,9} there are distinctive peaks at $(M - 30)^+$ and/or $(M - 60)^+$ corresponding to the loss of NO and N_2O_2 , whereas the $(M - 16$



peak which is usually present for heterocyclic *N*-oxides is weak.⁹

¹³C N.m.r. spectroscopy proves to be of particular value for the study of these heterocycles. In addition to resonances attributable to the CH₂ and CH of the norbornane skeleton, (5) has peaks at 166.8 and 116.2 p.p.m. which are assigned to the carbons at positions 4 and 3 respectively of the oxadiazole ring by comparison with those reported¹⁰ for 3,4-dimethylfuroxan (156.1 and 113.8 p.p.m.). The corresponding values for tricyclodecane furoxan (3) are 167.9 and 117.6 p.p.m. In the case of dicyclopentadiene furoxan (6) the detection of four furoxan ring carbon resonances (165.8, 164.1, 115.8, and 114.5) provides definitive evidence for the existence of two isomers (6A) and (6B). Likewise the product resulting from the oxidation of camphorquinone dioxime is also a mixture of isomers (2A) and (2B).⁴ The chemical shifts for C-4 of these norbornane-type furoxans, falling in the range 169 to 164 p.p.m., differ markedly from those found for unstrained analogues such as dimethylfuroxan (156.6) and diphenylfuroxan (156.1 p.p.m.). For C-3 the displacement is less pronounced with values of 118 to 114.5 p.p.m. for norbornane-furoxans compared with 113.8 and 114.2 for dimethyl- and diphenyl-furoxans respectively.

Crystal-structure determinations were undertaken for tricyclodecane furoxan (3) and dicyclopentadiene furoxan (6). In each case the structure was solved and refined to *R* ≈ 0.10

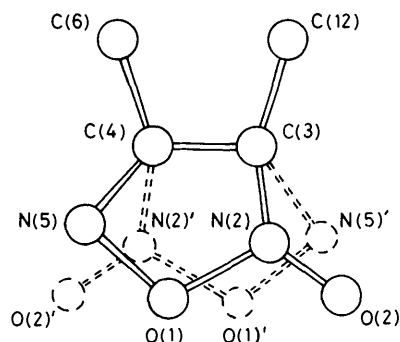


Figure 1. Two orientations of the furoxan ring present in the crystal

when disorder in the orientation of the furoxan ring became apparent; in (3) 15% of the molecules are in the alternate orientation shown in Figure 1, and in (6) 50%. Disorder of this type has been also reported for diphenyl- and tetramethylenefuroxans.^{11,12} It was therefore impossible to determine the bond lengths and angles with the accuracy we had hoped, but the stereochemistry of the molecules is established (Figure 2). The propenylene group in (6) is *endo*, consistent with the framework of the parent alkene being retained throughout the synthetic sequence. For (3) the trimethylene group is *exo*, as it is for the tricyclodecanone from which it is derived.* In view of the disorder problems substantial discussion of bond lengths is not justifiable, but it is noteworthy that for both (3) and (6) the bond O(1)–N(2) appears long, 1.47(2) and 1.54(2) Å respectively, compared to unstrained analogues¹³; other studies¹⁻¹⁴ have led us to associate a long bond at this position with ease of thermal decomposition, and in turn with a large angle C(12)–C(3)–N(2) (148° and 158° here).

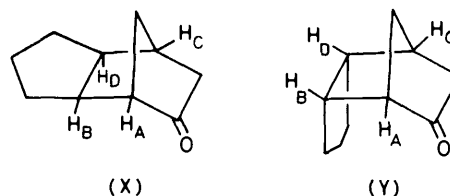
The present technique would appear to provide a general synthetic route to strained furoxans from cycloalkenes which are readily available from Diels-Alder cycloadditions of dienes such as cyclopentadiene and furan. The generation of bisnitrile oxides and di-isocyanates *via* the thermolysis of these furoxans will be described in subsequent publications.

Experimental

Mass spectra (70 eV ionisation potential) were measured using an AEI MS902 instrument. Varian CFT20 and Perkin-Elmer 257 spectrometers were used to record ¹³C n.m.r. and i.r. spectra respectively.

Synthesis of the Furoxans (2),(3),(5), and (6).—**HAZARD WARNING:** Low molecular-weight furoxans and some of their precursors are highly energetic compounds and should be

* ¹³C N.m.r. spectroscopy demonstrates that the 8-oxotricyclo-[5.2.1.0^{2,6}]decane supplied by Aldrich Chemical Co. is one isomer. The absence in the 360 MHz ¹H n.m.r. spectrum of observable couplings between the bridgehead protons H_A and H_B, and between H_C and H_D, is taken as strong evidence for structure (X) with the trimethylene group arranged *exo*, rather than the *endo*-trimethylene compound (Y).



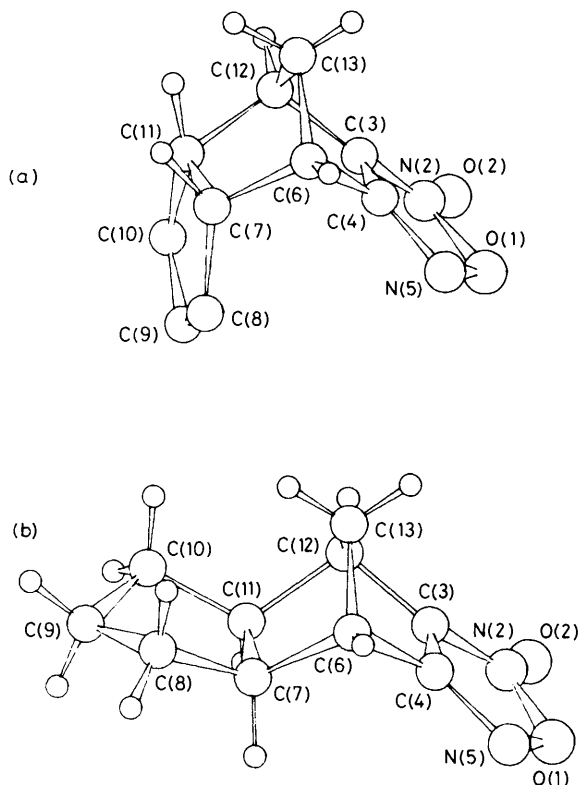


Figure 2. Stereochemistry found for (a) dicyclopentadiene furoxan (6), and (b) tricyclodecane furoxan (3). For (6) the hydrogens on C(8), C(9), and C(10) are omitted since there is disorder in the location of the ethylenic link [C(8)–C(9) or C(9)–C(10)]

handled with due caution. For example, (6) decomposes explosively on the gramme scale when heated to 80–85 °C.

4,5,6,7-Tetrahydro-4,7-methanobenzofurazan 1-Oxide (Norbornene Furoxan) (5).—Dinitrogen trioxide (containing an excess of nitric oxide to minimise risk of forming peroxy by-products) was prepared by mixing streams of nitric oxide (80 ml min⁻¹) and air (40 ml min⁻¹), and then allowing them time to react. The resulting gas mixture was passed through a deoxygenated solution of norbornene (20.0 g, 213 mmol) in dry pentane–diethyl ether (1 : 1; 250 ml) maintained between –5 and +2 °C until brown fumes of nitrogen oxides were visible above the surface (after ca. 0.5 h). The mixture was purged with nitrogen and the solid product was filtered off, washed with cold pentane, dried, and recrystallised from dichloromethane to yield white crystals of norbornene pseudonitrosite (7) (18.1 g, 53 mmol, 49%), m.p. 133–135 °C (lit.,⁶ 135 °C); ν_{\max} (Nujol) 1 550 cm⁻¹ (NO₂).

A solution of the pseudonitrosite (7) (15.0 g, 44 mmol) in dioxan–DMF (200 ml; 9 : 1) was heated under reflux until the colour changed from blue–green to yellow (after ca. 3 h), cooled, and the dioxan removed under reduced pressure. The residue was added to water (100 ml) and the resulting precipitate filtered off, dried, and recrystallised from toluene to afford the nitro-oxime (9) (9.1 g, 54 mmol, 61%) as white crystals, m.p. 164–166 °C (lit.,⁶ 167 °C); ν_{\max} (Nujol) 3 260 (OH), 1 680 (C=N), and 1 555 cm⁻¹ (NO₂).

Chlorosulphonic acid (30 ml) in DMF (60 ml) was added to a solution of the nitro-oxime (9) (4.93 g, 32.8 mmol) in DMF (25 ml). After 30 min the mixture was poured onto cold water and the pH adjusted to ca. 10 by the addition of 20% NaOH. Extraction with dichloromethane (3 × 50 ml), evaporation of

the solvent, and recrystallisation of the resulting solid from toluene afforded norbornene furoxan (5) (3.17 g, 20.8 mmol, 72%) as a white crystalline solid, m.p. 70 °C (Found: C, 55.5; H, 5.4; N, 18.3. C₇H₈N₂O₂ requires C, 55.3; H, 5.3; N, 18.4%); ν_{\max} (Nujol) 1 655 and 1 555 cm⁻¹ (furoxan *N*-oxide); δ_c (CDCl₃, Me₄Si) 166.7 and 116.2 (furoxan ring C), 47.7, 25.9 and 25.8 (CH₂), and 38.1 and 37.1 (CH); m/z 152 (*M*⁺), 136 ([*M*–O]⁺), 122 ([*M*–NO]⁺), 92 ([*M*–N₂O₂]⁺), and 67 (100%).

4a,5,7a,8-Tetrahydro-4,8-methano-4H-indeno[5,6-c][1,2,5]-oxadiazole 1- and 3-Oxides (Dicyclopentadiene Furoxan) (6).—A pre-mixed stream of nitric oxide (150 ml min⁻¹) and air (75 ml min⁻¹) was passed through a deoxygenated solution of dicyclopentadiene (66.0 g, 500 mmol) in dry pentane (1 l) maintained at ca. 0 °C until brown fumes of nitrogen oxides were visible above the surface (after ca. 3 h). The mixture was purged with nitrogen and the solid product was filtered off, washed with hot methanol, dried, and recrystallised from dichloromethane–pentane to yield dicyclopentadiene pseudonitrosite (69.0 g, 180 mmol, 72%), m.p. 145–150 °C (lit.,⁷ 151–154 °C); ν_{\max} (Nujol) 1 555 cm⁻¹.

The pseudonitrosite (10.0 g, 26 mmol) dissolved in dioxan (250 ml) was heated under reflux until the colour changed from blue–green to yellow (after ca. 40 min). Removal of the solvent afforded a yellow oil which slowly crystallised on cooling. Washing with ether–pentane gave a pale yellow crystalline solid (6.2 g, 34 mmol, 63%), a mixture of the isomeric dicyclopentadiene nitro-oximes, m.p. 135–150 °C (lit.,⁷ 129–132 and 171 °C).

The nitro-oxime from the previous stage (2.20 g, 11.5 mmol) was treated with a standardised DMF–SO₃ mixture (containing 5% excess of SO₃ over the stoichiometric amount required for the dehydration process); a further amount of DMF (1.5 ml) was added to ensure the mixture was completely liquid at room temperature. After 0.5 h at room temperature, the mixture was poured into water (60 ml), filtered through Celite and 1 M aqueous NaOH added to give pH 9–10. The resulting precipitate was extracted into toluene, washed with water, dried over anhydrous sodium carbonate, and passed through an alumina column to remove traces of DMF. Treatment with charcoal, evaporation of the solvent, and recrystallisation from pentane yielded a mixture of the isomeric dicyclopentadiene furoxans (6) (1.35 g, 7.1 mmol, 62%) as a white crystalline solid, m.p. 98–100 °C (Found: C, 63.1; H, 5.3; N, 14.7. C₁₀H₁₀N₂O₂ requires C, 63.2; H, 5.7; N, 14.6%); ν_{\max} (Nujol) 1 655 and 1 540 cm⁻¹ (furoxan *N*-oxide); δ_c (CDCl₃, SiMe₄) 165.8, 164.0, 115.8, and 114.6 (furoxan ring C), 133.0, 131.8, 129.7, and 128.8 (alkene CH), 48.0, 47.9, 33.8, and 33.5, (CH₂), and 53.9, 53.1, 43.2, 42.0, and 40.9 (8CH); m/z 190 (*M*⁺), 160 ([*M*–NO]⁺), 130 ([*M*–N₂O₂]⁺), and 124 (100%).

4a,5,6,7a,8-Hexahydro-4,8-methano-4H-indeno[5,6-c]-oxadiazole 1-Oxide (Tricyclodecane Furoxan) (3).—This compound was prepared from 8-oxotricyclo[5.2.1.0^{2,6}]decane via its isonitroso-derivative and the corresponding dioxime by the method of Ackrell *et al.*,⁴ and isolated as a white crystalline solid, m.p. 63–64 °C (lit.,⁴ m.p. 62–63 °C); ν_{\max} (Nujol) 1 670 and 1 550 cm⁻¹ (furoxan *N*-oxide); δ_c (CDCl₃, Me₄Si) 167.9 and 117.6 (furoxan ring C), 41.6, 31.0, 30.9, and 28.5 (CH₂), and 46.3, 46.0, 42.2, and 40.5 (CH); m/z 192 (*M*⁺), 162 ([*M*–NO]⁺), and 132 ([*M*–N₂O₂]⁺).

4,5,6,7-Tetrahydro-4,8,8-trimethyl-4,7-methanobenzofurazan 1-Oxide (Camphor Furoxan) (2).—This compound was prepared from camphorquinone dioxime as described³, m.p. 143–144 °C (lit.,³ 144 °C); ν_{\max} (Nujol) 1 674 and 1 550 cm⁻¹

(furozan *N*-oxide); $\delta_c(\text{CDCl}_3, \text{Me}_4\text{Si})$ 168.8, 166.0, 117.1, and 116.1 (furozan ring C), 59.3, 59.2, 51.6, and 51.3 (CMe and CMe₂), 47.5 and 46.4 (CH), 32.4, 25.0, and 24.7 (4CH₂), 20.2, 17.6, 9.4, and 8.7 (6CH₃); m/z 194 (M^+), 178 ($[M - O]^+$), 164 ($[M - \text{NO}]^+$), 135 (100%), and 134 ($[M - \text{N}_2\text{O}_2]^+$).

X-Ray Crystal Structure Analysis of Dicyclopentadiene Furoxan (6).—*Crystal data.* C₁₀H₁₀N₂O₂, M , 190, monoclinic, $a = 10.86(2)$, $b = 10.81(2)$, $c = 7.77(2)$ Å, $\beta = 92.1^\circ$, $D_m = 1.42$ g cm⁻³, $Z = 4$, $D_c = 1.39$ g cm⁻³, space group $P2_1/c$, Cu- K_α radiation, $\lambda = 1.5418$ Å.

Summary of structure determination. The layers $hk0$ to $hk6$ and $h0l$ to $h2l$ were recorded on Weissenberg photographs and intensities measured by the S.R.C. microdensitometer service. The structure was solved by direct methods, and refinement converged at $R = 0.08$ for 744 reflections; allowance was made for six hydrogen atoms, for anisotropic vibration parameters of all carbon atoms and O(2) and O(2)', and for alternate disordered positions of all N and O atoms each with site occupancy 0.5 (see Figure 1). Some of the vibration parameters of C(8), C(9), and C(10) appear high, not surprisingly, since they cover the disorder of $-\text{CH}_2-\text{CH}=\text{CH}-$ and $-\text{CH}=\text{CH}-\text{CH}_2-$.

X-Ray Crystal Structure Analysis of Tricyclodecane Furoxan (3).—*Crystal data.* C₁₀H₁₂N₂O₂, M 192, orthorhombic, $a = 7.04(2)$, $b = 19.25(4)$, $c = 6.90(2)$ Å at 120 K, $D_m = 1.33$ g cm⁻³ (at 293 K), $Z = 4$, $D_c = 1.36$ g cm⁻³, space group $P2_12_12_1$, Cu- K_α radiation, $\lambda = 1.5418$ Å.

Summary of structure determination. The layers $hk0$ to $hk6$ and $0k1$ to $3k1$ were recorded on a Nonius Weissenberg camera with nitrogen gas stream cooling equipment; intensities were measured by the S.R.C. microdensitometer service, yielding 721 unique reflections. The structure was solved by direct methods and refinement converged at $R = 0.11$; allowance was made for hydrogen atoms at eight of the stereochemically expected positions, for anisotropic vibration parameters of C, N, and O atoms, and for the alternate positions O(2) and O(2) with site occupancies 0.85 and 0.15 (see Figure 1). It was clear from the vibration parameters that

alternative sites for O(1), N(2), N(5) and perhaps other atoms too, would need to be included to describe properly the disorder.

Tables of positional and vibrational parameters and of observed and calculated structure factors have been deposited as a Supplementary publication [SUP. No. 23458 (11 pages)].

Acknowledgements

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