Preparation and Dienophilic Reactions of Nitrosyl Cyanide

By **Peter Horsewood** and **Gordon W. Kirby,*** Department of Chemistry, University of Glasgow, Glasgow G12 8QQ

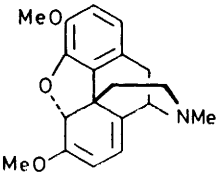
Nitrosyl chloride and silver cyanide react at low temperatures to give nitrosyl cyanide (ONCN) which undergoes 1,4-cycloaddition reactions with conjugated dienes to form the corresponding 2-cyano-3,6-dihydro-2*H*-1,2-oxazines. Thus, the alkaloid, thebaine (1), reacted with a limited quantity of nitrosyl cyanide to form a single adduct (2; R = H, X = CN) convertible into 14-cyanamidocodeinone (3); with an excess of nitrosyl cyanide the related *N*-cyanomethyl derivative (2; R = X = CN) was formed. Similarly, *N*-cyano-oxazines have been prepared from buta-1,3-diene and its 2,3-dimethyl, 1-methoxycarbonyl-4-methyl, 1-cyano-4-methyl, and 1,4-bisethoxycarbonyl derivatives. Base-induced rearrangements reactions leading to a pyridone (7), a pyrrolinone (11), and a mixture of dihydrofurans (14) are described.

C-NITROSO-COMPOUNDS undergo Diels-Alder reactions with conjugated dienes to form dihydro-1,2-oxazines [1] which may serve as intermediates for the synthesis of, *inter alia*, 4-amino-alcohols.[2] The scope and limitations of these reactions have been reviewed.[3] Our observation [4] of reversible addition of nitroso-arenes to the diene system of thebaine (1), to give the corresponding adducts (2; R = H, X = Ar), prompted us to design new types of dienophilic *C*-nitroso-compounds capable of rapid, and effectively irreversible, addition to electron-rich dienes. Two structural criteria were considered important: [5] in the system C–N=O, the carbon atom (i) should be trigonal or digonal rather than tetrahedral, thereby reducing steric effects, and (ii) should form part of an electron-withdrawing group. We record here the preparation and reactions of nitrosyl cyanide (O=N–C≡N) which satisfies both criteria for a powerful, electrophilic dienophile.[6]

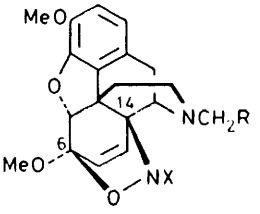
Nitrosyl cyanide was originally proposed as an intermediate in the photolysis of nitric oxide–cyanogen mixtures containing nitrogen dioxide [7] but recent attempts [8] to confirm this proposal have been unsuccessful. Related studies [9] on the transient formation of nitrosyl cyanide in the gas phase have, apparently, not yet been re-investigated. Our original preparation [6] of nitrosyl cyanide from silver cyanide and nitrosyl chloride has, so far, remained the method of choice for chemical and physical studies on this cyanogen analogue of the familiar nitrosyl halides. Publications have appeared on the microwave [10] and infrared [11] spectra of nitrosyl cyanide. The CN bond dissociation energy has been measured [12] and the thermal [13] and photochemical [8] decompositions have been studied. Theoretical accounts of the properties of nitrosyl cyanide have also appeared.[14]

RESULTS AND DISCUSSION

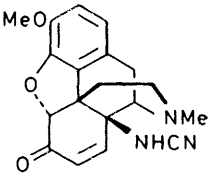
Initially, thebaine (1) was selected as an appropriate [4] diene to monitor the formation of nitrosyl cyanide. In a typical experiment, nitrosyl chloride (4 mmol) was added to a stirred suspension of dry silver cyanide (7.5 mmol) in chloroform containing *ca.* 1% ethanol at −20 °C. After 3 min, thebaine (2 mmol) was added in chloroform. The reaction mixture was chromatographed to afford thebaine (31%) and a product (34%) having an elemental composition corresponding to (2; R = H, X = CN). The n.m.r. spectrum of this product showed characteristic [4] features similar to those of the cyclo-adducts of thebaine and nitroso-arenes. Additionally, an i.r. band at 2 205 cm^{-1} indicated the presence of a cyanamide group. Prolonged contact of (2; R = H, X = CN) with alumina caused selective hydration of the cyanamide group to yield the urea (2; R = H, X = $CONH_2$). The structure of the cyclo-adduct (2; R = H, X = CN) was confirmed by catalytic hydrogenation over platinum oxide to give 14-cyanamidocodeinone (3). Since this transformation removed one oxygen atom and produced an αβ-unsaturated ketone with retention of the NCN moiety, the NO-bridge of the cyclo-adduct must be attached through nitrogen at C-14 and oxygen at C-6, rather than the reverse. The stereochemistry of (2; R = H, X = CN) is assigned by analogy with that of the adducts of thebaine and nitroso-arenes.[4]



(1)



(2)



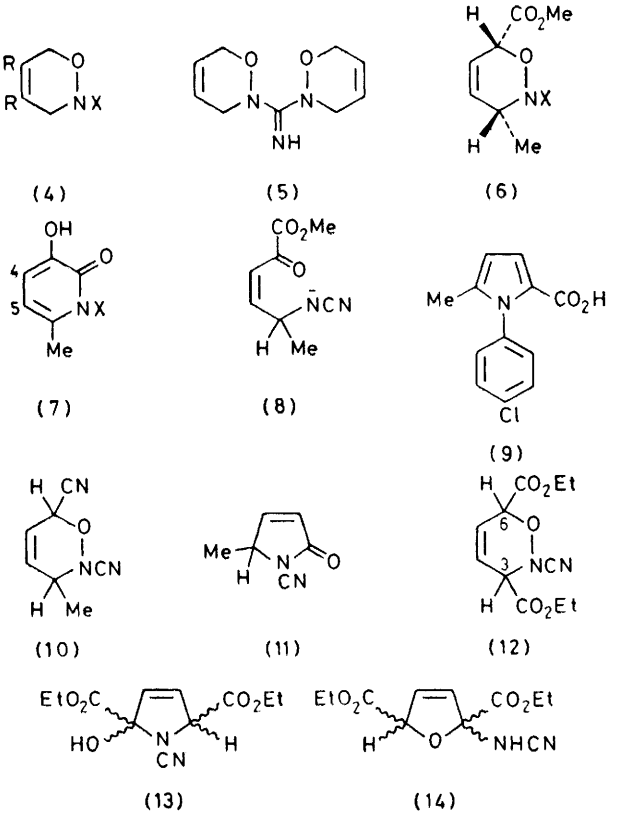
(3)

The yield of (2; R = H, X = CN) from thebaine varied (11—46%) from experiment to experiment and appeared to depend, *inter alia*, on the quality of the silver cyanide, the rate of stirring, and the purity of the solvent, chloroform [the presence of ethanol (1%) was beneficial]. To simplify the procedure, the reaction of nitrosyl chloride with silver cyanide was studied in the absence of

solvent. Nitrosyl chloride (20 mmol) was condensed at −78 °C onto finely powdered, dry silver cyanide (37 mmol) in an evacuated or partially evacuated vessel. The vigorously stirred mixture was allowed to warm up gradually. At *ca.* −60 °C nitrosyl cyanide was detected as a blue-green gas ($\lambda_{max.}$ 738 nm), and, by −20 °C, this gas had filled the reaction vessel. Addition of thebaine (13 mmol) in dichloromethane then produced the adduct (2; R = H, X = CN) (13%) along with unchanged thebaine (61%). In an attempt to achieve a higher conversion, thebaine (3.3 mmol) was treated with a large excess of nitrosyl cyanide prepared, in the absence of solvent, from nitrosyl chloride (11 mmol) and silver cyanide (19 mmol). However, a new cyclo-adduct (2; R = X = CN) was obtained as the major product. The n.m.r. spectrum of this compound lacked a singlet for an *N*-methyl group but showed an AB-quartet, τ 6.20 and 6.35 (*J* 11 Hz), attributable to an *N*-cyanomethylene group in a chiral molecule. The presence of a second cyano-group in the product was indicated by a new, weak i.r. band at 2 245 cm^{-1}. Hydration of (2; R = X = CN) on alumina gave the urea (2; R = CN, X = $CONH_2$) and treatment with sodium methoxide gave the *O*-methylisourea [2; R = CN, X = C(NH)OMe]. As expected, (2; R = H, X = CN) was converted into (2; R = X = CN) with an excess of nitrosyl cyanide.

The adducts (2) are stable compounds which do not dissociate detectably in solution and which, significantly, show molecular ion peaks in their mass spectra. In contrast, the adducts of thebaine and nitroso-arenes generally form more slowly and dissociate readily, and reversibly, in solution at ambient temperatures.[4] These observations suggested that nitrosyl cyanide was, as predicted, powerfully dienophilic, at least towards the electron-rich, methoxydiene system of thebaine. The reactions of nitrosyl cyanide with simple butadiene derivatives were next explored to determine the scope of cyclo-adduct formation.

Nitrosyl cyanide and butadiene reacted at −20 °C to form the *N*-cyano-oxazine (4; R = H, X = CN) as a distillable oil identical with a sample prepared from the known[15] oxazine (4; R = X = H) and cyanogen bromide. Hydration of (4; R = H, X = CN) with dilute sulphuric acid gave the crystalline urea (4; R = H, X = $CONH_2$) and treatment with the parent oxazine (4; R = X = H) gave the guanidine (5) which was characterised as the crystalline hydrochloride. Similarly, 2,3-dimethylbutadiene and nitrosyl cyanide afforded the oily adduct (4; R = Me, X = CN) which was converted into the crystalline urea (4; R = Me, X = $CONH_2$). The reaction of nitrosyl cyanide with methyl hexa-*trans*-2,*trans*-4-dienoate was studied next to determine the orientation and stereochemistry of addition to an unsymmetrical diene. The oily product (6; X = CN) (70%) appeared from its .m.r. spectrum to consist of a single isomer and was found to be identical spectroscopically with a sample prepared from the parent oxazine (6; X = H), of known[2] structure and stereochemistry, by treatment with cyanogen bromide. Thus, nitrosyl cyanide conforms with 1-chloronitrosocyclohexane[2] and nitrosobenzene derivatives[16] in its mode of addition to methyl hexa-*trans*-2,*trans*-4-dienoate. An attempt was made to hydrolyse the ester (6; X = CN) to the corresponding acid using aqueous methanolic sodium hydroxide. Instead, the crystalline pyridone (7; X = CN) was obtained in high yield. The same product was obtained nearly quantitatively from the ester by the action of triethylamine. The structure (7; X = CN) was supported by, *inter alia*, i.r. bands at 3 280, 2 255, 1 668, and 1 630 cm^{-1} and n.m.r. signals at τ[$(CD_3)_2SO$] 0.03 (br s, OH), 3.31 (d, *J* 7 Hz, 4-H), 3.85 (q, *J* 7 Hz and 1.5 Hz, 5-H), and 7.69 (d, *J* 1.5 Hz, Me).



The formation of (7; X = CN) is considered to involve removal of the proton α to the ester group followed by, or concerted with, cleavage of the N–O bond to give the cyanamide anion (8). Attack by this anion at the ester group would lead ultimately to (7; X = CN). An analogous transformation has been reported[16] for the adduct (6; X = 4-ClC_6H_4). However, the corresponding pyridone (7; X = 4-ClC_6H_4) was accompanied by the pyrrole (9) which became the major product at higher reaction temperatures.

The ability of nitrosyl cyanide to react rapidly even with conjugated dienes carrying electron-withdrawing substituents was explored further. With 1-cyanopenta-*trans*-1, *trans*-3-diene an oily product was obtained which decomposed upon attempted distillation. The crude material, which was judged spectroscopically to contain

the expected adduct (10), was, therefore, treated directly with triethylamine in ether. The resulting, crystalline product gave spectroscopic data consistent with a pyrrolinone structure (11): $\nu_{max.}$ 2 250 and 1 737 cm^{-1}; $\tau(CDCl_3)$ 2.57 (dd, *J* 6 and 2 Hz, 4-H), 3.80 (dd, *J* 6 and 1.5 Hz, 3-H), 5.27 (m, 5-H), and 8.47 (d, *J* 7 Hz, Me). Presumably, conversion of (10) into an intermediate anion (8; CO_2Me replaced by CN) was followed by cyclisation with expulsion of cyanide to give (11).

The adduct formed from diethyl hexa-*trans*-2, *trans*-4-dienedioate was assigned, on spectroscopic grounds, the expected structure (12). Again, attempted distillation led to decomposition. Treatment of the crude adduct with triethylamine gave a crystalline, isomeric product which appeared from the n.m.r. spectrum to be a mixture (*ca.* 1.5 : 1) of stereoisomers. Two structures, (13) and (14), were considered for this product. The former would arise, as described before, by initial removal of a proton from C-6 of the adduct (12). However, ionisation at C-3 would lead, in analogous fashion, to the dihydrofuran (14). A clear distinction between these alternatives could not be made spectroscopically but structure (14) is favoured on the basis of (i) the low-field signals, τ 4.40 and 4.61 for each stereoisomer, for 5-H, and (ii) the presence of fragment peaks in the mass spectrum corresponding to loss of HNCN and H_2NCN.

The foregoing results show that nitrosyl cyanide reacts generally with conjugated dienes to form cyclo-adducts. The orientation of addition, at least to thebaine (1) and methyl hexa-*trans*-2, *trans*-4-dienoate, corresponds to that of more familiar *C*-nitroso-compounds. A limitation to the preparative value of this route to *N*-cyano-oxazines arises from the presence of impurities, notably nitrosyl chloride and nitrogen dioxide, in the crude nitrosyl cyanide, which may react competitively with the diene or olefinic product. An alternative, 'clean' procedure involving thermal cleavage of the adduct of nitrosyl cyanide and 9,10-dimethylanthracene [5,17] will be described in a later paper.

EXPERIMENTAL

General Methods.—M.p.s were determined with a Kofler hot-stage apparatus. Except where otherwise stated n.m.r. spectra were obtained for deuteriochloroform solutions at 60 MHz with tetramethylsilane as internal standard.

Preparation of Nitrosyl Cyanide.—Silver cyanide, precipitated by slow addition, with stirring and cooling, of aqueous silver nitrate (*ca.* 40%) to an equimolar amount of aqueous potassium cyanide (*ca.* 40%), was washed with water, dried thoroughly *in vacuo* over silica gel in the dark at room temperature, and finely powdered before use. Nitrosyl chloride (97%, B.D.H. Chemicals Ltd.) was used without further purification. Typical conditions for the preparation of nitrosyl cyanide were as follows.

Nitrosyl chloride (1.0 ml) was condensed onto silver cyanide (5.0 g) at −70 °C in an evacuated flask (500 ml capacity) containing glass beads to assist stirring. The mixture was allowed to warm up slowly, with vigorous, magnetic stirring, to −25 °C by which temperature a blue–green gas was seen to fill the vessel. Solutions of various dienes (see below) were then admitted to the flask. Small samples of nitrosyl cyanide were readily purified by low temperature distillation, the blue gas, $\lambda_{max.}$ 738 nm with vibrational fine structure, being appreciably more volatile than the major impurities, *e.g.* nitrosyl chloride and cyanogen chloride (see also ref. 13).

CAUTION. Although nitrosyl cyanide decomposed only slowly in the gas phase in the dark even at room temperature, vigorous decomposition of condensed samples of impure material was occasionally observed. Other workers [18] have reported explosions during the purification of nitrosyl cyanide. Purification on a large scale by bulb-to-bulb distillation is, therefore, not recommended.

An alternative procedure, involving formation of nitrosyl cyanide in solution at −20 to −25 °C is exemplified below.

6β,14β-(N-*Cyanoepoxyimino*)-6,14-*dihydrothebaine* (2; R = H, X = CN).—Nitrosyl chloride (0.2 ml) was added to a stirred suspension of dry silver cyanide (1 g) in chloroform (10 ml) containing *ca.* 1% ethanol at −20 °C. Thebaine (1) (600 mg) in chloroform (10 ml) was added after 3 min. and stirring was continued as the mixture was allowed to warm up slowly to room temperature. The reaction mixture was filtered through Celite and the filtrate was evaporated. Chromatography of the residue on neutral, grade III alumina and elution with ethyl acetate–benzene (1 : 1) gave, successively, the *cyclo-adduct* (2; R = H, X = CN) (240 mg), m.p. 149—150 °C (decomp.) (from EtOH) (Found: C, 65.1; H, 5.9; N, 11.35. $C_{20}H_{21}N_3O_4$ requires C, 65.4; H, 5.8; N, 11.4%) (Found: *m/e* 367.153 5. $C_{20}H_{21}N_3O_4$ requires *M*, 367.153 4); $\nu_{max.}$ (Nujol) 2 205 and 1 635 cm^{-1}; τ 3.35 (br s, 1-H and 2-H), 3.66 (q, *J* 9 and *ca.* 1 Hz, 7-H), 4.00 (d, *J* 9 Hz, 8-H), 5.47 (d, *J ca.* 1 Hz, 5-H), 6.20 (s, ArOMe), 6.43 (s, 6-OMe), and 7.54 (s, NMe) and thebaine (1) (186 mg).

The same product (2; R = H, X = CN) was obtained, together with unchanged thebaine, by addition of thebaine (4.0 g) in dichloromethane (30 ml) to gaseous nitrosyl cyanide, at −20 °C, prepared as before from nitrosyl chloride (1.0 ml) and silver cyanide (5.0 g).

6β,14β-(N-*Carbamoylepoxyimino*)-6,14-*dihydrothebaine* (2; R = H, X = $CONH_2$).—The cyclo-adduct (2; R = H, X = CN) (130 mg) was absorbed on a column of neutral, grade III alumina and partially eluted with ethyl acetate to ensure intimate contact with the absorbant. After 24 h at room temperature, elution with ethyl acetate–ethanol (95 : 5) gave (2; R = H, X = CN) (20 mg) and the urea (2; R = H, X = $CONH_2$) (82 mg), m.p. 177 °C (decomp) (from EtOH) (Found: C, 62,0; H, 6.1; N, 11.0. $C_{20}H_{23}N_4O_5$ requires C, 62.3; H, 6.2; N, 10.9%); $\nu_{max.}$ (Nujol) 3 380, 3 300, 3 200, and 1 697 cm^{-1}; τ 3.37 (m, 1-H and 2-H), 3.97 (s, 7-H and 8-H), 4.36 (br s, NH_2, exchangeable with D_2O), 5.28 (d, *J* 6.5 Hz, 9-H), 5.43 (s, 5-H), 6.20 (s, ArOMe), 6.40 (s, 6-OMe), and 7.54 (s, NMe).

6β,14β-(N-*Cyanoepoxyimino*)-N-*cyanomethyl*-6,14-*dihydro*-N-*northebaine* (2; R = X = CN).—Thebaine (1 g) in dichloromethane (15 ml) was added to nitrosyl cyanide, prepared as before from nitrosyl chloride (0.5 ml) and silver cyanide (2.5 g), at −20 °C. The mixture was allowed to warm up to room temperature and was then filtered through Celite. The filtrate was evaporated and the residue was chromatographed on grade III, neutral alumina. Elution with ethyl acetate gave the *cyclo-adduct* (2; R = X = CN) (408 mg), m.p. 184—185 °C (decomp.) (from MeOH–$CHCl_3$) (Found: C, 64.6; H, 5.3; N, 14.3. $C_{21}H_{20}N_4O_4$ requires C, 64.3; H, 5.1; N, 14.3%) (Found: *m/e* 392.149 0. $C_{21}H_{20}N_4O_4$ requires *M*, 392.148 5); $\nu_{max.}$ (Nujol) 2 245 (weak),

2 215, and 1 635 cm^{-1}; τ 3.34 (m, 1-H and 2-H), 3.66 (q, *J* 9 and 1.5 Hz, 7-H), 4.03 (d, *J* 9 Hz, 8-H), 5.47 (d, *J* 1.5 Hz, 5-H), 6.22 (s, ArOMe), 6.20 and 6.35 (ABq, *J* 11 Hz, NCH_2CN), and 6.43 (s, 6-OMe). The same product was obtained (44%) from the *N*-methyl compound (2; R = H, X = CN) and an excess of nitrosyl cyanide.

6β,14β-(N-*Carbamoylepoxyimino*)-N-*cyanomethyl*-6,14-*dihydro*-N-*northebaine* (2; R = CN, X = $CONH_2$).—The cyanamide (2; R = X = CN) was hydrolysed on alumina as described before for the *N*-methyl compound (2; R = H. X = CN). The resulting *urea* (2; R = CN, X = $CONH_2$) (90%) had m.p. 187—188.5 °C (decomp.) (from MeOH) (Found: C, 61.7; H, 5.1; N, 13.8. $C_{21}H_{22}N_4O_5$ requires C, 61.45; H, 5.4; N, 13.65%); $\nu_{max.}$ (Nujol) 3 490, 3 400, 2 250 (weak), 1 710, and 1 672 cm^{-1}; τ 3.35 and 3.42 (ABq, *J* 8 Hz, 2-H and 1-H), 4.00 (br s, 7-H and 8-H), 4.38 (br s, NH_2, exchangeable with D_2O), 5.13 (d, *J* 6.5 Hz, 9-H), 5.43 (s, 5-H), 6.22 (s, ArOMe and NCH_2CN), and 6.42 (s, 6-OMe); *m/e* 410.

N-*Cyanomethyl*-6,14-*dihydro*-6β,14β-[N-(C-*methoxyformimidoyl*)-*epoxyimino*]-N-*northebaine* [2; R = CN, X = MeOC(=NH)].—Sodium methoxide (52 mg) in methanol (5 ml) was added to a suspension of the cyanamide (2; R = X = CN) (110 mg) in methanol (15 ml). The mixture was stirred at 50 °C for 0.5 h to give a clear solution. The chloroform-soluble product was crystallised from methanol to give the O-*methylisourea* [2; R = CN, X = MeOC(=NH)] (53 mg), m.p. 180 °C (decomp.) (Found: C, 62.3; H, 5.7; N, 13.4. $C_{23}H_{24}N_4O_5$ requires C, 62.25; H, 5.7; N, 13.2%); $\nu_{max.}$ (Nujol) 3 355 and 1 660 cm^{-1}; τ 3.32 and 3.39 (ABq, *J* 8 Hz, 2-H and 1-H), 3.51 (br s, NH, exchangeable with D_2O), 3.92 (q, *J* 8.9 and 1.5 Hz, 7-H), 4.25 (d, *J* 8.5 Hz, 8-H), 5.41 (d, *J* 1.5 Hz, 5-H), 5.43 (d, *J* 6.5 Hz, 9-H), 6.17 (s, ArOMe), 6.20 [s, MeOC(=NH)], 6.32 (s, NCH_2CN), and 6.38 (s, 6-OMe); *m/e* 424.

14-*Cyanoaminocodeinone* (3).—The cyclo-adduct (2; R = H, X = CN) (367 mg) was hydrogenated in methanol over platinum oxide (50 mg) at room temperature and pressure for 5 h. The mixture was filtered and the filtrate was evaporated. The oily residue crystallised from ethanol to afford 14-*cyanoaminocodeinone* (110 mg), m.p. 201 °C (Found: C, 67.8; H, 5.9; H, 12.1. $C_{19}H_{19}N_3O_3$ requires C, 67.65; H, 5.7; N, 12.5%); $\nu_{max.}$ ($CHCl_3$) 3 220, 2 215, and 1 695 cm^{-1}; τ 3.30 (s, 1-H and 2-H), 3.42 and 3.70 (ABq, *J* 10.3 Hz, 8-H and 7-H), 4.88 (br s, NH, exchangeable with D_2O), 5.04 (s, 5-H), 6.18 (s, ArOMe), and 7.60 (s, NMe); *m/e* 337.

2-*Cyano*-3,6-*dihydro*-2H-1,2-*oxazine* (4; R = H, X = CN).—(a) *From butadiene and nitrosyl cyanide.* Nitrosyl chloride (1.0 ml) was added to a stirred suspension of silver cyanide (5 g) in dichloromethane previously flushed with nitrogen, at −25 °C. After 5 min, buta-1,3-diene was passed slowly through the solution for 45 min. The mixture was allowed to warm up to room temperature and was then filtered through Celite. Evaporation of the filtrate gave an oil (1.08 g) which was chromatographed on neutral, grade III alumina. Elution with chloroform gave 2-*cyano*-3,6-*dihydro*-2H-1,2-*oxazine* (4; R = H, X = CN) (550 mg), b.p. 67 °C (1.5 mmHg) (Found: C, 54.5; H, 5.7; N, 25.5. $C_5H_6N_2O$ requires C, 54.5; H, 5.5; N, 25.4%) (Found: *m/e* 110.047 7. $C_5H_6N_2O$ requires *M*, 110.048 0); $\nu_{max.}$ (liq. film) 2 215 and 1 645 cm^{-1}; τ (220 MHz) 4.03 (m, $J_{4,5}$ 11.7 Hz, 4-H and 5-H), 5.45 (m, 6-H), and 6.02 (m, 3-H).

(b) *From* 3,6-*dihydro*-2H-1,2-*oxazine*. 3,6-Dihydro-2*H*-1,2-oxazine hydrochloride [15] (1.21 g) in water (15 ml) was added dropwise with stirring during 30 min to cyanogen bromide (1.2 g) in saturated aqueous sodium hydrogen carbonate (40 ml). After a further 30 min the mixture was extracted with ether (3 × 20 ml). Evaporation of the extract gave 2-cyano-3,6-dihydro-2*H*-1,2-oxazine (1.02 g), b.p. 56 °C (1 mmHg), which had spectroscopic properties identical with those of the material prepared by method (a). In contrast, addition of cyanogen bromide to the oxazine (4; R = X = H) in ether gave the guanidine (5) as a major by-product along with (4; R = H, X = CN). A reference sample of (5) was prepared as follows. The cyanamide (4; R = H, X = CN) (110 mg) and the oxazine (4; R = X = H) hydrochloride (121.5 mg) were kept in ethanol for 4.5 h at room temperature. The resulting guanidine (5) hydrochloride (140 mg) had m.p. 207—209 °C (decomp.); τ[$(CD_3)_2SO$] 0.6 (br s, NH_2), 4.0 (s, olefinic H), 5.39 (m, 6-H), and 5.78 (m, 4-H).

2-*Carbamoyl*-3,6-*dihydro*-2H-1,2-*oxazine* (4; R = H, X = $CONH_2$).—The cyanamide (4; R = H, X = CN) (110 mg) and 30% aqueous sulphuric acid (2 ml) were heated slowly to the boiling point and then under reflux for 15 min. The resulting clear solution was cooled and extracted with chloroform (3 × 10 ml). The extracts yielded an oil (105 mg) which crystallised slowly. Recrystallisation from benzene gave 2-*carbamoyl*-3,6-*dihydro*-2H-1,2-*oxazine* (4; R = H, X = $CONH_2$), m.p. 64—65 °C (Found: C, 46.9; H, 6.2; N, 21.9. $C_5H_8N_2O_2$ requires C, 46.9; H, 6.3; N, 21.9%); $\nu_{max.}$ ($CHCl_3$) 3 545, 3 430, 1 695, 1 685, and 1 665 cm^{-1}; τ 4.13 (m, 4-H and 5-H), 4.30 (br s, NH_2, exchangeable with D_2O), 5.53 (m, 6-H), and 5.92 (m, 3-H); *m/e* 128.

2-*Cyano*-3,6-*dihydro*-4,5-*dimethyl*-2H-1,2-*oxazine* (4; R = Me, X = CN) *and the Derived Urea* (4; R = Me, X = $CONH_2$).—2,3-Dimethylbuta-1,3-diene (1.5 g) in dichloromethane (15 ml) was added to nitrosyl cyanide, prepared as before from nitrosyl chloride (1.0 ml) and silver cyanide (5.0 g), at −25 °C. The oily product, isolated as described before, was chromatographed on neutral, grade III alumina. Elution with benzene and distillation of the major component gave the cyanamide (4; R = Me, X = CN), b.p. 68 °C (0.4 mmHg); $\nu_{max.}$ (liq. film) 2 215 cm^{-1}; τ 5.71 (m, 6-H), 6.28 (m, 3-H), and 8.35 (br s, Me); *m/e* 138. The cyanamide (4; R = Me, X = CN) (100 mg) in methanol (1 ml) and 50% aqueous sulphuric acid (1 ml) were heated at 70 °C for 1 h. The resulting 2-*carbamoyl*-3,6-*dihydro*-4,5-*dimethyl*-2H-1,2-*oxazine* (4; R = Me, X = $CONH_2$) (60 mg) had m.p. 103—104 °C (from benzene) (Found: C, 53.7; H, 7.7; N, 17.8. $C_7H_{12}N_2O_2$ requires C, 53.8; H, 7.7; N, 17.9%); $\nu_{max.}$ ($CHCl_3$) 3 550, 3 430, and 1 678 cm^{-1}; τ 4.55 (br s, NH_2, exchangeable with D_2O), 5.78 (m, 6-H), 6.08 (m, 3-H), and 8.37 (m, Me); *m/e* 156.

2-*Cyano*-3,6-*dihydro*-6-*methoxycarbonyl*-3-*methyl*-2H-1,2-*oxazine* (6; X = CN).—Methyl hexa-*trans*-2, *trans*-4-dienoate (methyl sorbate) (1.0 g) in dichloromethane (15 ml) was treated with nitrosyl cyanide as in the foregoing preparation of (4; R = Me, X = CN). Chromatography of the product on neutral, grade III alumina and elution with chloroform gave the cyanamide (6; X = CN) (1.0 g), b.p. 121 °C (1.5 mmHg); $\nu_{max.}$ (liq. film) 2 215 and 1 765 cm^{-1}; τ 4.04 (m, 4-H and 5-H), 5.03 (m, 6-H), 5.90 (m, 3-H), 6.19 (s, OMe), and 8.64 (d, *J* 7 Hz, 3-Me); *m/e* 182. An identical product was obtained from the known [2] oxazine (6; X = H) and cyanogen bromide by the method described above for the preparation of (4; R = H, X = CN).

1-*Cyano*-3-*hydroxy*-6-*methyl*-2-*pyridone* (7; X = CN).—The foregoing cyanamide (6; X = CN) (193 mg) in metha-

nol (1 ml) was treated with 5% methanolic sodium hydroxide (0.5 ml). A precipitate quickly formed which dissolved upon addition of 5% methanolic sodium hydroxide (0.5 ml) and water (0.5 ml). The mixture was neutralised with 2M-hydrochloric acid and the resulting crystalline precipitate was filtered off. The filtrate was extracted with chloroform and the extracts were evaporated to yield more crystalline product. The combined solids crystallised from methanol to give 1-*cyano*-3-*hydroxy*-6-*methyl*-2-*pyridone* (7; X = CN) (110 mg), m.p. 191—193 °C (decomp.) (Found: C, 56.0; H, 4.2; N, 18.8. $C_7H_6N_2O_2$ requires C, 56.0; H, 4.0; N, 18.7%); $\lambda_{max.}$ (EtOH) 212 (ε 11 800) and 323 nm (7 700); $\lambda_{max.}$ (EtOH–NaOH) 223 (ε 10 850), 265 (4 470), and 349 nm (8 320); i.r. and n.m.r. spectra are recorded in the main text.

Alternatively, the cyanamide (6; X = CN) (100 mg) was treated with triethylamine, either in ether or without solvent (a vigorous, exothermic reaction occurred), to give a product (80 mg) with spectroscopic properties identical with those of (7; X = CN) prepared by the foregoing method.

2,6-*Dicyano*-3,6-*dihydro*-3-*methyl*-2H-1,2-*oxazine* (10).—1-Cyanopenta-*trans*-1, *trans*-3-diene (sorbonitrile) (1.5 g) in dichloromethane (15 ml) was treated in the usual way with nitrosyl cyanide prepared from nitrosyl chloride (1.0 ml) and silver cyanide (5 g). The crude product was washed with light petroleum (b.p. 60—80 °C) to remove sorbonitrile and then was extracted with benzene. Evaporation of the extracts gave the crude cyanamide (10) as a viscous oil (1.15 g); $\nu_{max.}$ (liq. film) 2 220 and 1 660 cm^{-1}; τ 4.01 (m, 4-H and 5-H), 4.81 (m, 6-H), 5.75 (m, 3-H), and 8.60 (d, *J* 7 Hz, Me); *m/e* 149. The oil decomposed upon attempted distillation.

1-*Cyano*-5-*methyl*-Δ^3-*pyrrolinone* (11).—The foregoing, crude cyanamide (10) (350 mg) in ether (10 ml) was treated with a catalytic amount of triethylamine at room temperature for 24 h. Crystallisation of the product from ether gave the *pyrrolinone* (11) (165 mg), m.p. 77 °C (Found: C, 58.7; H, 5.15; N, 23.15. $C_6H_6N_2O$ requires C, 59.0; H, 4.95; N, 22.9%) (Found: *m/e* 122.048 1. $C_6H_6N_2O$ requires *M*, 122.048 0); spectroscopic data are given in the main text.

2-*Cyano*-3,6-*bisethoxycarbonyl*-3,6-*dihydro*-2H-1,2-*oxazine* (12).—Diethyl hexa-*trans*-2, *trans*-4-diendioate (0.8 g) in dichloromethane was treated with gaseous nitrosyl cyanide as described before. The cyanamide (12) was obtained as an oil (0.85 g); $\nu_{max.}$ (liq. film) 2 230 and 1 760 cm^{-1}; τ 3.80 (m, 4-H and 5-H), 4.80 (m, 6-H), 5.35 (m, 3-H), 5.68 (q, *J* 7 Hz, CH_2), 5.72 (q, *J* 7 Hz, CH_2), and 8.68 (t, *J* 7 Hz, 2 × Me); *m/e* 254. This oil decomposed upon attempted distillation.

2-*Cyanoamino*-2,5-*bisethoxycarbonyl*-2,5-*dihydrofuran* (14).—The foregoing crude cyanamide (12) in ether (10 ml) was treated with a catalytic amount of triethylamine at room temperature for 24 h. The product crystallised from benzene to afford the *dihydrofuran* (14) (183 mg) as a mixture of stereoisomers, m.p. 68—78 °C (Found: C, 51.9; H, 5.6; N, 10.9. $C_{11}H_{14}N_2O_5$ requires C, 52.0; H, 5.55; N, 11.0%) (Found: *m/e* 254.090 0. $C_{11}H_{14}N_2O_5$ requires *M*, 254.090 3); $\nu_{max.}$ (KBr) 3 200, 2 215, 1 757, and 1 740 cm^{-1}. The n.m.r. spectrum indicated a mixture of isomers in the ratio, *ca.* 1.5 : 1. Signals for the major isomer are given first; τ 3.45 (dd, *J* 6 and 2 Hz, 3-H), 3.62 (br s, NH, exchangeable with D_2O), 4.05 (dd, *J* 6 and 3 Hz, 4-H), 4.40 (dd, *J* 3 and 2 Hz, 5-H), 5.71 (q, *J* 7 Hz, CH_2), and 8.70 (t, *J* 7 Hz, Me), and τ 3.45 (dd, *J* 6 and 2 Hz, 3-H), 3.85 (br s, NH, exchangeable with D_2O), 4.01 (dd, *J* 6 and 3 Hz, 4-H), 4.61 (dd, *J* 3 and 2 Hz, 5-H), 5.81 (q, *J* 7 Hz, CH_2), and 8.68 (t, *J* 7 Hz, Me).

We thank the S.R.C. for financial support. The work reported in this paper was carried out in the Department of Chemistry, University of Technology, Loughborough.

[9/1784 *Received*, 29*th October*, 1979]

REFERENCES

[1] O. Wichterle, *Coll. Czech. Chem. Comm.*, 1947, **12**, 292; Y. A. Arbuzov, *Docklady Akad. Nauk S.S.S.R.*, 1948, **60**, 993.
[2] *E.g.* B. Belleau and Yum-Kin Au-Young, *J. Amer. Chem. Soc.*, 1963, **85**, 64.
[3] J. Hamer and M. Ahmad, ' 1,4-Cycloaddition Reactions,' ed. J. Hamer, Academic Press, New York, 1967, ch. 12.
[4] K. W. Bentley, P. Horsewood, G. W. Kirby, and Serjinder Singh, *Chem. Comm.*, 1969, 1411; G. W. Kirby, K. W. Bentley, P. Horsewood, and Serjinder Singh, *J.C.S. Perkin I*, 1979, 3064.
[5] G. W. Kirby, *Chem. Soc. Rev.*, 1977, **6**, 1.
[6] Preliminary communication: P. Horsewood and G. W. Kirby, *Chem. Comm.*, 1971, 1139.
[7] R. G. W. Norrish and F. F. R. Smith, *Trans. Faraday Soc.*, 1928, **24**, 620.
[8] C. M. Keary, B. G. Gowenlock, and J. Pfab, *J.C.S. Perkin II*, 1978, 242; J. K. Tyler, personal communication.
[9] N. Basco, J. E. Nicholas, R. G. W. Norrish, and W. H. J. Vickers, *Proc. Roy. Soc.*, 1963, **A272**, 147; J. P. Galvin and N. O. Pritchard, *J. Phys. Chem.*, 1964, **68**, 1035; N. Basco and R. G. W. Norrish, *Proc. Roy. Soc.*, 1965, **A283**, 291.
[10] R. Dickinson, G. W. Kirby, J. G. Sweeny, and J. K. Tyler, *J.C.S. Faraday II*, 1978, **74**, 1393; *J.C.S. Chem. Comm.*, 1973, 241.
[11] E. A. Dorko and L. Buelow, *J. Phys. Chem.*, 1975, **62**, 1869.
[12] B. G. Gowenlock, C. A. F. Johnson, C. M. Keary, and J. Pfab, *J.C.S. Perkin II*, 1975, 351.
[13] J. D. Illige and W. L. Jolly, *Inorg. Chem.*, 1977, **16**, 2637.
[14] C. Bjorkman, H. Johansen, B. Bak, and B. Roos, *Chem. Phys.*, 1977, **24**, 355; B. G. Gowenlock and L. Radom, *Austral. J. Chem.*, 1978, **31**, 2349.
[15] Yu. A. Arbuzov and A. A. Onishchenko, *Doklady Akad. Nauk S.S.S.R.*, 1962, **146**, 1075.
[16] G. Kresze and J. Firl, *Chem. Ber.*, 1966, **99**, 3695.
[17] J. E. T. Corrie, G. W. Kirby, and R. P. Sharma, *J.C.S. Chem. Comm.*, 1975, 915.
[18] Professors R. N. Haszeldine and B. G. Gowenlock, personal communications.