Silver(I)-catalyzed Oxidation of Cyclic Secondary Amines with Peroxodisulphate [1]

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Oxidation of piperidines, pyrrolidine, azetidine, perhydroazepine, and perhydroazocine with aqueous alkaline sodium peroxodisulphate in the presence of silver nitrate gave 1,1'-bipiperidines, a trimer of 1-pyrroline, 1,1'-biazetidine, 1,1'-biperhydroazepine together with 1-formylperhydroazepine, and 1-formylperhydroazocine, respectively.

An electron-transfer process in the silver(I)-catalyzed oxidation with peroxodisulphate has recently been recognized.[2-4] In the presence of silver(I) ion, peroxodisulphate decomposes according to equations (1) and (2): [5]

$$S_2O_8^{2-} + Ag^+ \longrightarrow SO_4^{-\bullet} + SO_4^{2-} + Ag^{2+} \quad (1)$$

$$SO_4^{-\bullet} + Ag^+ \longrightarrow SO_4^{2-} + Ag^{2+} \quad (2)$$

Caronna *et al.* and Walling *et al.* revealed that in the silver(I)-catalyzed oxidation of alcohols, silver(II) ion abstracts an electron from the oxygen atom to give alkoxy-radicals [equation (3)].[2,3]

$$ROH + Ag^{2+} \longrightarrow RO^{\bullet} + Ag^+ + H^+ \quad (3)$$

Hence, it is expected that aminyl radicals are generated in the oxidation of amines under alkaline conditions [equation (4)].

$$R_2NH + Ag^{2+} \longrightarrow R_2N^{\bullet} + Ag^+ + H^+ \quad (4)$$

Although Bacon *et al.* reported that treatment of aliphatic amines with an aqueous alkaline solution of sodium peroxodisulphate in the presence of silver nitrate gave aldehydes or ketones *via* imine intermediates, the yield being low and variable in the case of secondary amines, they did not refer to the intermediacy of aminyl radicals.[6] We describe here the silver(I) catalyzed oxidation of cyclic secondary amines with peroxodisulphate, which can be considered to involve aminyl radicals as intermediates.

Results and Discussion

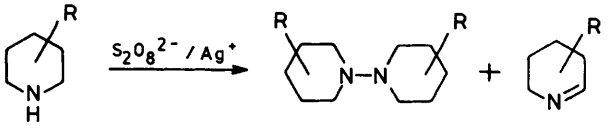
The oxidation of the piperidines (1) gave the 1,1'-biperidines (2) (See Table). V.p.c. analysis of the ethereal extract of the reaction mixture revealed that 2,3,4,5-tetrahydropyridines (3) were formed as sole by-products, the ratio of 1,1'-bipiperidines (2) to 2,3,4,5-tetrahydropyridines (3) being high (4.9—31) except in the case of 2-methylpiperidine (0.6).

Since 2-methylpiperidine (1b) and 3-methylpiperidine (1c) both have an asymmetric centre, (±)- and *meso*-isomers occur in the corresponding 1,1'-bipiperidines. Although the diastereoisomeric mixture of 3,3'-dimethyl-1,1'-bipiperidine (2c) was inseparable, that of 2,2'-dimethyl-1,1'-bipiperidine (2b) was separated into the (±)-and *meso*-isomers. Assignment of the diastereoisomers rests on the comparison on v.p.c. and t.l.c. of the optically pure (*S,S*)-2,2'-dimethyl-1,1'-bipiperidine (*S,S*)-(2b) ($[\alpha]_D^{20}$ + 179° in EtOH) produced from (*S*)-2-methylpiperidine (*S*)-(1b)($[\alpha]_D^{20}$ 36° in hexane)[7] with the two diastereoisomers.

Table. Silver(I)-catalyzed oxidation of piperidines with peroxodisulphate

Piperidine	Product yield (%) [a,b]	
(1a)	(2a) 48 (61)	(3a) (2)
(1b)	(±)-(2b) 5 (9)	(3b) (26)
	meso-(2b) 3 (7)	
(1c)	(2c) 30 (62) [c]	(3c) (2)
(1d)	(2d) 24 (39)	(3d) (8)
(1e)	(2e) 14	

[a] Isolated yield. [b] Values in parentheses are yield determined by v.p.c. [c] Inseparable diastereoisomeric mixture.

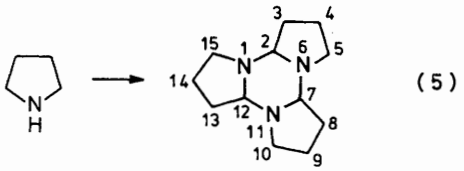


(1) (2) (3)

a; R = H
b; R = 2-Me
c; R = 3-Me
d; R = 4-Me
e; R = 4-Ph

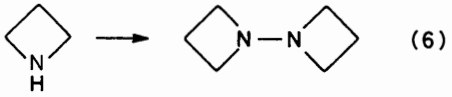
For the 1,1'-bipiperidines, which are interesting compounds in the conformational analysis,[8] preparative methods have only been reported for 1,1'-bipiperidine (2a), and all of these require several tedious and costly steps if one wants to start with piperidine.[9,10] Furthermore, overall yields obtained by using these known procedures are usually low (at most 10%). In contrast, our present method involves a very simple preparative procedure which guarantees a high yield (48%).

The oxidation of pyrrolidine (4) afforded a 1-pyrroline trimer, *i.e.* 1,6,11-triazatetracyclo[10.3.0.0^{2,6}.0^{7,11}]pentadecane (5), exclusively [equation (5)]. Its molecular formula was established by elemental analysis and cryoscopic measurements. A mass spectroscopic analysis suggested that it decomposes under the measurement conditions into the corresponding monomer, 1-pyrroline (6). Its $^{13}C\{^1H\}$ n.m.r. spectrum($CDCl_3$) indicated four peaks at δ_C 81.96 (C-2, -7, -12), 45.79 (C-5, -10, -15), 27.96 (C-3, -8, -13), and 20.37 p.p.m. (C-4, -9, -14) in complete agreement with its apparent C_3 symmetry. The ^1H off-resonance decoupled ^{13}C n.m.r. spectrum clearly showed three triplets and a doublet, in accord with the presence of nine methylene and three methyne carbons in a



(4) (5) 50% (5)

(6)



(7) (8) < 5% (6)

molecule with C_3 symmetry.* The presence of a proton attached to the sp^2 carbon was precluded by its ^1H n.m.r. spectrum, which showed complex multiplets at $\delta_H(CDCl_3)$ 3.1 (6 H), 2.4 (3 H), and 1.9 (12 H). Hence, the structure of the trimer is represented by compound (5).

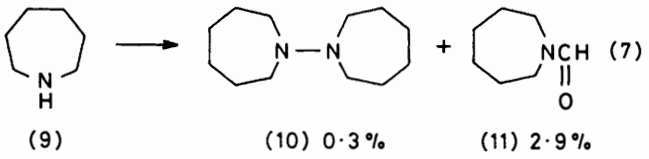
The preparation and the structure of the 1-pyrroline trimer have been ambiguous because of its thermal and acid lability.[11,12] Although the liquid thought to be the 1-pyrroline trimer was obtained by Fuhlhage and Van der Werf,[12] it was never isolated in the pure form and its physical properties were not characterized. Thus, the structure of the 1-pyrroline trimer has been established for the first time in the present work.

Oxidation of azetidine (7) gave 1,1′-biazetidine (8) [equation (6)] and an uncharacterized compound together with polymeric materials. In spite of various attempts compound (8) could not be isolated without the uncharacterized compound.†

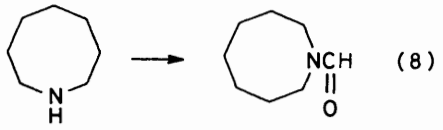
Oxidation of perhydroazepine (9) gave 1,1′-biperhydroazepine (10) and 1-formylperhydroazepine (11) [equation (7)], together with a large amount of polymeric material. In the oxidation of perhydroazocine (12), 1-formylazocine (13) was the sole isolated product [equation (8)] from the ethereal extract of the reaction mixture, a large part of which was polymeric material.

It is worth mentioning that *N,N*-coupling reactions were observed in the oxidation of azetidine (7), the piperidines (1), and perhydroazepine (9). While oxidative *N,N*-coupling of aromatic secondary amines to the corresponding hydrazines has been accomplished with various agents,[15] that of aliphatic or cyclic secondary amines has not been observed previously. Thus, our result is the first example of direct *N,N*-coupling of non-aromatic secondary amines.

Mechanistically, the present reaction may be explained by



(9) (10) 0·3% (11) 2·9% (7)



(12) (13) 1% (8)

the assumption that aminyl radicals are involved as intermediates (Scheme). Since in the absence of silver nitrate 1,1′-bipiperidine was not formed, we consider that the silver(II) ion generated according to equations (1) and (2) abstracts an electron from the nitrogen atom of a cyclic secondary amine (14) to give an aminyl radical (15) [see the Scheme and equation (4)]. The combination of radicals gives the *N,N*-coupling products (16), and the hydrogen abstraction from the neighbouring CH bond affords the cyclic imines (17). While cyclic imines generated from pyrrolidine and from piperidines generally give the corresponding trimers (18),[16] the cyclic imine from 2-methylpiperidine stands as the monomer (3b), probably for steric reasons.[17] Cyclic imines formed from perhydroazepine (9) and from perhydroazocine (12) are likely to be hydrolyzed to give amino-aldehydes (19). Although such compounds (19) under the reaction conditions would for the most part undergo intermolecular condensation to give polymers, to some extent further oxidation with $S_2O_8^{2-}$–Ag^+ occurs to form the radical cation (20) by an electron-transfer process. The radical cation (20) cleaves to give a formyl cation (21) which reacts with the remaining cyclic amine to give the formamide (22). It is worth noticing that the products depend largely on the ring size of the cyclic amines in this reaction.

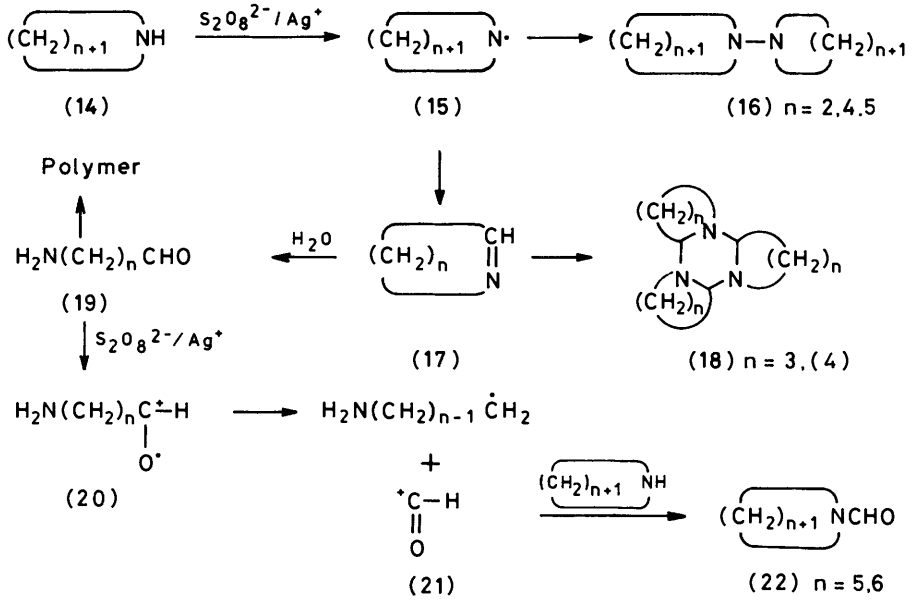
Experimental

60 MHz, 90 MHz, and 100 MHz ^1H n.m.r., and 15 MHz, 20 MHz, and 22.4 MHz ^{13}C n.m.r. spectra were recorded on JEOL C60-HL, Varian EM-390, JEOL MH-100, JEOL FX 60, Varian CFT-20, and JEOL FX90Q spectrometers, respectively. Mass spectra were measured on a Hitachi RMU-6D mass spectrometer. I.r. spectra were determined on Jasco DS-430 or A-202 grating infrared spectrometers. Vapour phase chromatography (v.p.c.) was conducted in most cases with a stainless-steel column (2 m × 4 mm) or an aluminium column (2 m × 3/8 in.), both of which were packed with 15% Triton-X305 on 60—80 mesh Uniport B; occasionally a stainless steel column (2 m × 6 mm) with 5% FFAP on 60—80 mesh Uniport B was used. Optical rotations were measured with an automatic Yanaco OR-50 polarimeter by using a quartz cell with a 1.0-cm path length. M.p.s are uncorrected. Ether refers to diethyl ether throughout.

Oxidation of Piperidine (1a).—A 25% aqueous solution of sodium peroxodisulphate (11.9 g, 0.05 mol) was added dropwise below 10 °C to a stirred mixture of the piperidine (1a) (4.3 g, 0.05 mol), sodium hydroxide (4.0 g, 0.10 mol), and a catalytic amount of silver nitrate (43 mg, 0.25 mmol) in water (50 ml) and the mixture was then stirred for an additional 2.5 h. After the reaction mixture had been saturated with sodium chloride, it was extracted with ether and the ethereal extract

* If the nitrogen inversion is faster than the n.m.r. time-scale, (5) satisfies apparent C_3 symmetry regardless of its conformations, since all three methyne protons are supposedly axial. Details about the assignment of signals in the ^{13}C n.m.r. spectrum and the conformation of (5) will be reported elsewhere.

† Nelsen *et al.*[13] and Kirste *et al.*[14] reported the synthesis of compound (8) by a photochemical or a thermal decomposition of 1,1′-azoazetidine. They isolated it by preparative v.p.c. We tried to isolate it by adapting their conditions (OV-210, column temperature 150 °C), but found that it decomposed on the column.



Scheme. Tentative scheme for the silver(I)-catalyzed oxidation of cyclic secondary amines

was dried ($MgSO_4$). Evaporation of the extract under reduced pressure gave an oily residue (2.67 g) which was shown by v.p.c. to contain 1,1′-bipiperidine (2a) (97%) and the trimer of 2,3,4,5-tetrahydropyridine (3a) (3%). The residue was chromatographed on a silica-gel column using hexane–ethyl acetate (10 : 1) as eluant, to give compound (2a) (2.0 g, 48%). Evaporative distillation (room temp./0.5 mmHg) gave an analytically pure sample as colourless needles (m.p. 19.5—20.5 °C) (Found: C, 71.3; H, 12.1; N, 16.8. Calc. for $C_{10}H_{20}N_2$: C, 71.37; H, 11.98; N, 16.65%.); δ_H ($CDCl_3$) 2.9—2.7 (8 H, m), and 1.9—1.2 (12 H, m); δ_C ($CDCl_3$) 49.31 (t), 26.65 (t), and 24.89 p.p.m. (t); *m/e* 168 (M^+). Picrate: m.p. 153.5—154.0 °C (from EtOH–H_2O, 3 : 2) (lit.,[10] 153—154 °C). Compound (3a) was identical with an authentic sample by v.p.c. comparison.[16]

Oxidation of 2-*Methylpiperidine* (1b).—A 25% aqueous solution of sodium peroxodisulphate (71.4 g, 0.3 mol) was added dropwise below 10 °C to a stirred mixture of 2-methylpiperidine (1b) (19.8 g, 0.2 mol), sodium hydroxide (24 g, 0.6 mol), and silver nitrate (1.70 g, 0.01 mol) in water (300 ml) and the mixture was stirred for an additional 2.5 h. After saturation of the reaction mixture with sodium chloride, precipitated inorganic materials were filtered off. The filtrate was extracted with ether and the extract was dried ($MgSO_4$). Evaporation of the extract under reduced pressure gave an oily residue (9.6 g), which was shown by v.p.c. to contain of (±)-2,2′-*dimethyl*-1,1′-*bipiperidine* (±)-(2b) (18%), meso-2,2′-*dimethyl*-1,1′-*bipiperidine meso*-(2b) (14%), 2,3,4,5-tetrahydro-6-methylpiperidine (3b) (55%), unchanged 2-methylpiperidine (11%), and uncharacterized materials (2%). The residue was chromatographed on an alumina column, using hexane as eluant, to give (±) (2b) (0.94 g, 5%) and *meso*-(2b) (0.61 g, 3%), both as colourless oils.

For (±)-(2b): b.p. 70.0 °C at 0.9 mmHg (Found: C, 73.1; H, 12.3; N, 14.0. $C_{12}H_{24}N_2$ requires C, 73.41; H, 12.32; N, 14.27%.); δ_H ($CDCl_3$) 2.9 (1 H, m), 2.6—2.0 (2 H, m), 1.8—1.0 (6 H, m), and 1.02 (3 H, d); δ_C ($CDCl_3$) 54.53 (d), 43.98 (t), 35.68 (t), 26.87 (t), 25.28 (t), and 20.93 p.p.m. (q); *m/e* (70 eV) 196 (M^+).

For *meso*-(2b): b.p. 71.5 °C at 0.9 mmHg (Found: C, 73.2; H, 12.5; N, 14.1. $C_{12}H_{24}N_2$ requires C, 73.41; H, 12.32; N, 14.27%); δ_H ($CDCl_3$) 3.1—2.4 (3 H, m), 2.0—1.1 (6 H, m), and 1.10 (3 H, d); δ_C (in [$^2H_{14}$]diglyme at 100 °C) 58.38 (d), 48.96 (t), 36.69 (t), 27.74 (t), 24.55 (t), and 20.15 p.p.m. (q).[8]

Compound (3b) was identified by a v.p.c. comparison with an authentic sample.[17]

(S)-(+)-2-*Methylpiperidine* (S)-(1b)[7].—Resolution of a racemic mixture of 2-methylpiperidine with (+)-tartaric acid gave the salt, (+)-2-methylpiperidinium hydrogen tartarate, m.p. 64—65 °C (lit.,[7c] 65—66 °C). On treatment with alkali it was converted into (*S*)-(1b), $[\alpha]_D^{23.5}$ +36.4° (*c* 3.46 in hexane) [lit.,[7c] $[\alpha]_D^{15}$ 36.5° (*c* 4.90 in hexane)].

(*S,S*)-(+)-2,2′-*Dimethyl*-1,1′-*bipiperidine* (S,S)-(2b).—Oxidation of the (*S*)-isomer of compound (1b) was carried out in the same manner as that of the racemic mixture of 2-methylpiperidine to give (*S,S*)-(2b) as a colourless oil, $[\alpha]_D^{20}$ 179° (*c* 0.454 in EtOH). The peak of (±)-(2b) in v.p.c. coincided with that of (*S,S*)-(2b). Coincidence between (±)-(*S,S*)-(2b) and (2b) spots in t.l.c. was also confirmed.

Oxidation of 3-*Methylpiperidine* (1c).—3-Methylpiperidine (1c) (9.9 g, 0.1 mol) was oxidized in the same manner as piperidine. The reaction mixture was extracted with dichloromethane and the extract was dried ($MgSO_4$). Evaporation of the extract under reduced pressure gave an oily residue (6.4 g), which was shown by v.p.c. to contain 3,3′-*dimethyl*-1,1′-*bipiperidine* (2c) (93%) and the trimer of 2,3,4,5-tetrahydro-5 (or 3)-methylpyridine (3c) (3%). The residue was chromatographed on a silica-gel column, using hexane-ethyl acetate (5 : 1) as eluant, to give (2c) (3.0 g, 30%) as an inseparable diastereoisomeric mixture in the form of a colourless oil, b.p. 106 °C at 17 mmHg (Found: C, 73.3; H, 12.3; N, 14.0. $C_{12}H_{24}N_2$ requires C, 73.41; H, 12.32; N, 14.27%), δ_H ($CDCl_3$) 3.1—2.8 (4 H, m), 2.7—1.2 (14 H, m), and 0.9 (6 H, d); δ_C ($CDCl_3$) 57.04 (t), 56.65 (t), 48.63 (t), 48.27 (t), 31.97 (d), 33.47 (t), 25.81 (t), and 19.74 p.p.m. (q); *m/e* (70 eV) 196 (M^+).

Identification of compound (3c) was based on a v.p.c. comparison with a specimen, which was prepared by treatment

of 1-chloro-3-methylpiperidine with alkali (KOH–MeOH). In the ^{13}C n.m.r. spectrum of the specimen, all the signals (*ca.* 76 peaks) appeared at higher than δ_C 88 p.p.m. Its ^1H n.m.r. spectrum showed the absence of a proton attached to the sp^2 carbon. Hence, the specimen is not the monomer of 2,3,4,5-tetrahydro-3(or 5)-methylpyridine, but it is probably an isomeric mixture of the trimers of 2,3,4,5-tetrahydro-3(or 5)-methylpyridine.

Oxidation of 4-*Methylpiperidine* (1d).—4-Methylpiperidine (1d) (5.0 g, 0.05 mol) was oxidized in the same manner as piperidine (1a). The reaction mixture was extracted with ether, dried ($MgSO_4$), and concentrated under reduced pressure to give an oily residue (2.6 g), which was shown by v.p.c. to contain 4,4′-*dimethyl*-1,1′-*bipiperidine* (2d) (83%) and 2,3,4,5-tetrahydro-4-methylpyridine (3d) (17%). The residue was chromatographed on a silica-gel column using hexane–ethyl acetate (9 : 1) as eluant to give (2d) (1.18 g, 24%). Evaporative distillation (50 °C 0.5 mmHg) gave an analytically pure sample as a colourless oil wich solidified in the receiver, m.p. 27.0—28.0 °C, b.p. 63 °C at 0.5 mmHg (Found: C, 73.7; H, 12.4; N, 14.2. $C_{12}H_{24}N_2$ requires C, 73.41; H, 12.32; N, 14.27%); δ_H ($CDCl_3$) 2.9—2.7 (4 H, m), 2.5—2.2 (4 H, m), 1.8—1.0 (10 H, m), and 0.88 (6 H, d); δ_C ($CDCl_3$) 48.34 (t), 34.84 (t),31.23 (d), and 21.72 p.p.m. (q); *m/e* (70 eV) 196 (M^+). *Picrate*: m.p. 148.5—149.5 °C, needles (from MeOH) (Found C, 51.1; H, 6.5; N, 16.6. $C_{12}H_{24}N_2 \cdot C_6H_3N_3O_7$ requires C, 50.82; H, 6.40; N, 16.46%).

Identification of compound (3d) was based on a v.p.c. comparison with a specimen which was obtained as colourless crystals by treatment of 1-chloro-4-methylpiperidine with alkali (KOH–MeOH). In the ^{13}C n.m.r. spectrum of the specimen, all the signals (*ca.* 33 peaks) appeared at $\delta_C > 85$ p.p.m. Its ^1H n.m.r. spectrum showed the absence of the proton attached to the sp^2 carbon. Hence, the specimen is probably an isomeric mixture of the trimers of 2,3,4,5-tetrahydro-4-methylpyridine.

Oxidation of 4-*Phenylpiperidine* (1e).—A 25% aqueous solution of sodium peroxodisulphate (3.52 g, 15 mmol) was added dropwise at room temperature to a stirred mixture of 4-phenylpiperidine (1e) (1.61 g, 10 mmol), sodium hydroxide (2.0 g, 50 mmol), silver nitrate (85 mg, 0.05 mmol) water (100 ml), and acetonitrile (25 ml) [necessary to dissolve (1e)], and the mixture was stirred for an additional 2.5 h. After the reaction mixture had been saturated with sodium chloride, it was extracted with ether and the dried ($MgSO_4$) extract was concentrated under reduced pressure to give a residue (1.44 g). A few ml of ethanol was added and the precipitate was collected and washed with ethanol to give a spectroscopically pure sample of 4,4′-*diphenyl*-1,1′-*bipiperidine* (2e) (235 mg, 15%) as colourless crystals. It was dissolved in dichloromethane, filtered through a short column of activated alumina, and rinsed with dichloromethane. Evaporation of dichloromethane and crystallization of the residue from ethanol gave analytically pure compound (2e) as colourless prisms, m.p. 195.0—196.0 °C (Found: C, 82.3; H, 9.1; N, 8.9. $C_{22}H_{28}N_2$ requires C, 82.45; H, 8.81; N, 8.74%); δ_H ($CDCl_3$) 7.6—7.2 (10 H, m), and 3.4—3.2 (18 H, m); δ_C ($CDCl_3$) 146.22 (s), 128.38 (d), 126.87 (d), 126.09 (d), 48.90 (t), 43.05 (d), and 33.98 p.p.m. (t); *m/e* (70 eV) 320 (M^+).

Oxidation of Pyrrolidine (4).—A 25% aqueous solution of sodium peroxodisulphate (35.7 g, 0.15 mol) was added dropwise below 10 °C to a stirred mixture of pyrrolidine (4) (10.6 g, 0.15 mol), sodium hydroxide (12.g, 0.3 mol), and silver nitrate (127 mg, 0.75 mmol) in water (150 ml) and the mixture was stirred for 2.5 h. The reaction mixture was then saturated with sodium chloride, extracted with dichloromethane and the extract dried ($MgSO_4$) and concentrated under reduced pressure on an ice-bath. Ether (*ca.* 15 ml) was added and the precipitate was filtered off. The filtrate was evaporated under reduced pressure at 0 °C to give the almost pure 1-*pyrroline trimer* (5) (5.3 g, 50%) as a faint orange oil, which was found to be of satisfactory purity for n.m.r. spectra. Elution of the product through a neutral alumina column with ether followed by evaporation of the ether afforded an analytically pure sample of (5) as a colourless oil (Found: C, 69.2; H, 10.5; N, 20.1. $C_{12}H_{21}N_3$ requires C, 69.52; H, 10.21; N, 20.27%); $\nu_{max.}$ (neat) 2 790 cm^{-1} (Bohlmann band [18]); δ_H ($CDCl_3$) 3.2—3.0 (6 H, m), 2.5—2.1 (3 H, m), and 2.1—1.2 12H, m); δ_C ($CDCl_3$) 81.96 (d), 45.79 (t), 27.96 (t), and 20.37 p.p.m. (t); *m/e* (70 eV) 71 (M^+ of 1-pyrroline). Molecular weight, obtained by cryoscopic measurement of a benzene solution, was 229 ($C_{12}H_{21}N_3$ requires 209).

Oxidation of Perhydroazepine (9).—A 25% aqueous solution of sodium peroxodisulphate (59.5 g, 0.25 mol) was added dropwise below 10 °C to a stirred mixture of perhydroazepine (9) (19.8 g, 0.20 mol), sodium hydroxide (20.0 g, 0.5 mol), and silver nitrate (1.70 g, 0.05 mol) in water (250 ml) and the mixture was stirred for 17 h. After saturation of the reaction mixture with sodium chloride, the precipitated materials were filtered off. The filtrate was extracted with dichloromethane and the dried ($MgSO_4$) extract was concentrated under reduced pressure. The residue, most of which was polymer-like material, was distilled by Kugel–Rohr (100—150 °C/1 mmHg) to give a colourless oil. V.p.c. separation afforded 1,1′-*biperhydroazepine* (10) (0.13 g, 0.3%) and 1-formylperhydroazepine (11) (0.74 g, 2.9%), both as colourless oils.

For (10) (Found: C, 73.6; H, 12.3; N, 14.1. $C_{12}H_{24}N_2$ requires C, 73.41; H, 12.32; N, 14.27%); δ_H ($CDCl_3$) 2.8—2.6 (8 H, m) and 1.7—1.5 (16 H, m); δ_C ($CDCl_3$) 52.06 (t), 28.39 (t), and 26.65 p.p.m. (t).

For (11), b.p. 60.5—61.0 °C/0.5 mmHg (Found: C, 65.9; H, 10.4; N, 10.95. Calc. for $C_7H_{13}NO$: C, 66.10; H, 10.30; N, 11.02%); $\nu_{max.}$ (neat) 1 665 cm^{-1} (amido CO); its i.r. spectrum was superimposable upon that reported for *N*-formylperhydroazepine; [19] δ_H ($CDCl_3$) 8.12 (1 H, s), 3.6—3.4 (4 H, m), and 1.9—1.5 (8 H, m); δ_C ($CDCl_3$) 162.83 (d), 47.67 (t), 43.48 (t), 30.25 (t), 27.95 (t), 26.96, and 26.87 p.p.m.; *m/e* (70 eV) 127 (M^+).

Oxidation of Perhydroazocine (12).—A 25% aqueous solution of sodium peroxodisulphate (11.4 g, 48 mmol) was added dropwise below 10 °C to a stirred mixture of perhydroazocine (12) (4.52 g, 40 mmol), sodium hydroxide (4.8 g, 120 mmol), silver nitrate (34 mg, 0.2 mmol), and acetonitrile (12 ml) in water (50 ml) and the mixture was stirred for 7 h. The reaction mixture was then saturated with sodium chloride and extracted with ether. The dried ($MgSO_4$) extract was evaporated and the residue, most of which was polymer-like material, was distilled by Kugel–Rohr (120 °C/0.5 mmHg). Preparative v.p.c. of the distillate gave 1-formylperhydroazocine (13) as a colourless oil (52 mg, 1%). Its n.m.r. and i.r. spectra were superimposable upon those of the authentic sample which was prepared in the following manner.

Authentic Sample of 1-*Formylperhydroazocine* (13).—A mixture of perhydroazocine (12) (3.28 g, 29 mmol) and ethyl formate (11 g, 149 mml) was refluxed for 1 h. Evaporation under reduced pressure gave an oily residue (4.2 g). Kugel–Rohr distillation (100 °C/0.5 mmHg) of the residue (2.1 g) afforded compound (13) as a colourless *oil* (1.3 g, 64%) (Found: C, 67.9; H, 10.9; N, 9.6. $C_8H_{15}NO$ requires: C, 68.04; H, 10.71; N, 9.92%); $\nu_{max.}$ (neat) 1 675—1 655 cm^{-1}

(amido CO); δ_H ($CDCl_3$) 8.1 (1 H, s), 3.5—3.2 (4 H, m), and 1.9—1.3 (10 H, m); δ_C ($CDCl_3$) 162.90 (d), 49.10 (t), 43.93 (t), 27.30, 26.91, 25.84, 25.40, and 24.57 p.p.m.; *m/e* (70 eV) 141 (M^+).

Oxidation of Azetidine (7).—Azetidine (7.06 g, 124 mmol) was oxidized in a similar manner to piperidine. The dried (Na_2SO_4) ethereal extract was evaporated under reduced pressure to give an oily residue (0.565 g), which was shown by n.m.r. to contain 1,1′-biazetidine (8), as the main component and an uncharacterized compound A as a minor component along with some impurities. Although the impurities were removed by a Kugel–Rohr distillation (80 °C/0.5 mmHg), various attempts to separate (8) from A were unsuccessful. The structure of (8) was elucidated by comparison of the ^1H n.m.r. spectra with the reported spectrum [13] as well as on the basis of the ^{13}C n.m.r. spectra; δ_H ($CDCl_3$) 3.20 (8 H, t, *J* 7 Hz) and 2.00 (4 H, quintet, *J* 7 Hz); δ_C ($CDCl_3$) 49.80 (t) and 14.38 p.p.m. (t).

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