Nitroxide Radicals. Part XVIII.[1] Further Spectroscopic Investigation of the Banfield and Kenyon Nitroxide

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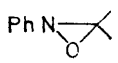
All proton coupling constants in the e.s.r. spectrum of the Banfield and Kenyon radical (the nitroxide formed on oxidation of the condensation product of phenylhydroxylamine and acetone) have been evaluated and assigned. The smallest splittings, a_H −0.34 (3H) and +0.41 G (2 H), the subject of previous dispute, are attributed to two sets of β-protons. Several new analogues of the Banfield and Kenyon radical were prepared for comparison.

THE product formed on reaction of acetone with phenylhydroxylamine, to which the oxaziridine [2] (1), dioxadiazine [3] (2), nitrone [4] (3; $R^1 = R^2 = Me$), and hydroxylaminonitrone [5] (4) structures have been previously ascribed, has now been shown [6] (crystallographic analysis) to be the isoxazolidine derivative (5a). The nitrones



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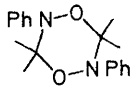

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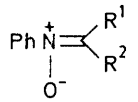

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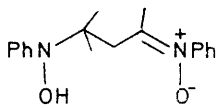

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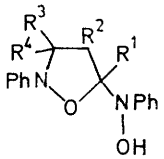

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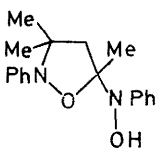
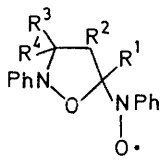


(5a)



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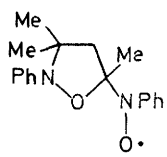
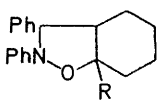


(6a)
Banfield and Kenyon nitroxide



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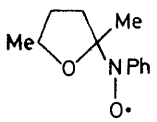

(8)

(3; $R^1 = R^2 = Me$) and (4) are probably precursors of (5a), the dimer (4) arising from the monomer (3; $R^1 = R^2 = Me$) by a base-catalysed (phenylhydroxylamine) aldol condensation and the final product (5a) by spontaneous cyclisation of the dimer (4). Oxidation of the hydroxylamine (5a) gives a red crystalline free radical, the Banfield and Kenyon nitroxide (6a), one of the first nitroxides to be isolated.[5] Surprisingly, and despite numerous previous attempts, the e.s.r. spectrum of this radical has never been satisfactorily interpreted. In particular there has been considerable disagreement over the origin and multiplicity of the hyperfine splitting (*ca.* 0.4 G) evident in the spectrum (Figure 1). This has been variously attributed to interaction of the unpaired electron with eight,[7] six,[8] five,[9,10] and three [11] unspecified (but see ref. 11) protons. However, previous interpretations have been based on the incorrect structure, corresponding to the nitroxide from (4). Using results from both n.m.r. and e.s.r. measurements on the Banfield and Kenyon nitroxide (6a) and several related radicals we now present a full spectral analysis and proton assignment.

Our interest in the Banfield and Kenyon (B–K) radical began with the observation, made in connection with other work, that the nitrone (3; $R^1 = Me$, $R^2 = Ph$), formed by reaction of nitrosobenzene with α-phenyldiazoethane, dimerised spontaneously to the hydroxylamine (5; $R^1 = R^3 = Ph$, $R^2 = H$, $R^4 = Me$), an analogue of the B–K radical precursor. The fine structure in the e.s.r. spectrum of the nitroxide derived from this hydroxylamine was not as well resolved as that in the spectrum of the B–K nitroxide and did not assist the inter-

[1] Part XVII, A. R. Forrester and R. Ramasseul, *J.C.S. Perkin I*, 1975, 1753.
[2] E. Bamberger and L. Rudolf, *Ber.*, 1907, **40**, 2236.
[3] E. Beckmann and J. Scheiber, *Annalen*, 1907, **353**, 235; J. Scheiber and H. Wolf, *ibid.*, 1908, **357**, 25.
[4] E. Bamberger, *Ber.*, 1924, **57**, 2082.
[5] F. H. Banfield and J. Kenyon, *J. Chem. Soc.*, 1926, 1612.
[6] R. Foster, J. Iball, and R. Nash, *J.C.S. Perkin II*, 1974, 1210.
[7] A. L. Buchachenko, *Optics and Spectroscopy*, 1963, **14**, 449.
[8] A. L. Buchachenko, 'Stable Free Radicals,' Consultants Bureau, New York, 1965, p. 123.
[9] F. Tudos, J. Heidt, and J. Ero, *Acta Chim. Acad. Sci. Hung.*, 1965, **45**, 245.
[10] K. Ishizu, T. Yamamoto, M. Kohno, A. Nakajima, and Y. Deguchi, *Tetrahedron Letters*, 1974, 1537.
[11] V. S. Griffith and G. R. Parlett, *Nature*, 1964, **204**, 69.

pretation of the latter. However, comparison of the n.m.r. spectra of these two nitroxides was more informative. That of the B–K radical (6a) showed in addition to a signal due to the *meta*-protons, two other peaks outside the δ 0—10 region, one downfield and the other upfield from tetramethylsilane. These correspond to two sets of protons with a_H +0.41 and a_H −0.34 G, respectively, while the spectrum of the nitroxide (6; $R^1 = R^3 = Ph$, $R^2 = H$, $R^4 = Me$) showed only a downfield peak with a_H +0.17 G. These spectral differences, which suggest that it is the ring methylene and the 5-methyl group in the B–K radical that are responsible for the unexplained splittings, determined the following specific objectives of the work: (a) to confirm that the *gem*-dimethyl group at C-3 did not give rise to detectable splitting in the e.s.r. spectrum; (b) to establish which of the two sets of β-protons had the positive and which the negative coupling constant; (c) to confirm that the protons of the C-4 methylene group were magnetically equivalent and so resolve the problem of the multiplicity of the hyperfine splitting. Fulfilment of these objectives clearly required further measurements on suitably substituted B–K radical analogues and to this end we examined available and new ways of producing such radicals, including spin trapping methods.

Ideally, nitroxides of type (6) with R^1 = Me or Ar and R^3, R^4 = t-alkyl, Ar, or H would have been most useful for spectral comparisons of the B–K radical and its analogue (6; $R^1 = R^3 = Ph$, $R^2 = H$, $R^4 = Me$). The preparation of these nitroxides by the nitrone condensation procedure would require cross-condensation of suitably substituted nitrones (3). Several attempts to effect such condensations were unavailing. Thus, the nitrone (3; $R^1 = Ph$, $R^2 = Me$) with (3; $R^1 = R^2 = Ph$), and with (3; $R^1 = H$, $R^2 = Ph$), under a variety of conditions gave none of the desired hydroxylamines. Aldonitrone self-condensation was also briefly examined and the known [12] hydroxylamine (5; $R^1 = R^3 = H$, $R^2 = Et$, $R^4 = Pr$) was prepared *via* the nitrone (3; $R^1 = H$, $R^2 = Pr$). However, hydroxylamines produced in this way from aldonitrones give nitroxides with an α-hydrogen atom. Generally such nitroxides are much less stable [13] in concentrated solution than those with t-alkyl groups flanking the nitrogen and considerable difficulty was encountered with the n.m.r. measurements on this nitroxide. Because of this no further examples of this type were prepared.

The hydroxylamine (7; R = PhNOH) which is the precursor of a B–K radical analogue (7; R = PhNO˙) has previously [14] been prepared by condensation of 1-morpholinocyclohexene with the nitrone (3; R^1 = Ph, $R^2 = H$). This reaction has now been extended to the preparation of four other hydroxylamines (5; R^1 = Me, $R^2 = R^3 = H$, R^4 = Ph; $R^1 = Pr^i$, $R^2 = R^3 = H$, R^4 = Ph; $R^1 = R^3$ = Ph, $R^2 = R^4 = H$; R^1 = Et, R^2 = Me, R^3 = Ph, $R^4 = H$) of this type. Interestingly, these hydroxylamines, like (7; R = PhNOH), (5; $R^1 = R^3$ = Ph, $R^2 = H$, R^4 = Me), and (5; $R^1 = R^3 = H$, R^2 = Et R^4 = Pr) but unlike the precursor of the B–K radical, are formed as mixtures of diastereoisomers satisfactory separation of which by crystallisation was only possible in one case, (7; R = PhNOH). We have not examined the above enamine addition in detail but presume that the isoxazolidine (7; R = morpholino) is an intermediate, the morpholino-group being displaced by reaction of (7; R = morpholino) with the nitrone or its hydrolysis product, phenylhydroxylamine. We were unable to test this possibility since, using enamines from morpholine, no intermediate of this type could be isolated. However, reaction of the enamine from pyrrolidine and cyclohexanone with the nitrone (3; R^1 = Ph, $R^2 = H$) gave the isoxazolidine (7; R = pyrrolidin-1-yl) as the sole product. [15] Several attempts to displace the pyrrolidin-1-yl group by phenylhydroxylamino by reaction of (7; R = pyrrolidin-1-yl) with phenylhydroxylamine or the nitrone (3; R^1 = Ph, $R^2 = H$) in neutral and acidic solution failed.

Spin trapping [16] provided only one e.s.r. spectrum useful for comparison with the B–K type radicals. Thus, photolysis of mixtures of di-t-butyl peroxide, 2,5-dimethyltetrahydrofuran, and nitrosobenzene gave the nitroxide (8) in easily detectable concentrations. Similar experiments with 2-methyl-2,3-dihydrobenzofuran and 2,3,5-triphenylisoxazolidine were less successful. The former gave a mixture of radicals, probably formed by hydrogen abstraction from the 2- and 3-positions of the dihydrobenzofuran followed by trapping with nitrobenzene, and the latter gave t-butoxy phenyl nitroxide [17] (a_N 14.5, $a_{o,p\text{-}H}$ 2.92, $a_{m\text{-}H}$ 0.99 G) or, when benzene was added as a cosolvent, diphenyl nitroxide. The inaccessibility of suitably substituted tetrahydrofurans prevented further exploitation of this source of model nitroxides.

Spectra.—Our initial impression that it was the 5-methyl and the 4-methylene groups which were responsible for the smallest splitting in the spectrum of the B–K radical was confirmed by the following observations. (i) Of the nitroxides examined, whose coupling constants are given in the Table, only those with 5-methyl and 4-methylene, *i.e.*, (8) and (6; R^1 = Me, $R^2 = R^3 = H$, R^4 = Ph), gave spectra closely similar to that of the B–K radical. Generally, the spectra of the others were less well resolved presumably because of minor differences in the coupling constants of diastereoisomers. (ii) Only those nitroxides with a primary or a secondary 5-alkyl substituent gave an n.m.r. signal at high field corresponding to a small (0.15—0.4 G) negative splitting.

[12] G. E. Utzinger and F. A. Regenass, *Helv. Chim. Acta*, 1954, **37**, 1892; A. D. Baker, J. E. Baldwin, D. P. Kelly, and J. De Barnardis, *Chem. Comm.*, 1969, 344; W. Kliegel, *Tetrahedron Letters*, 1967, 2627.

[13] A. R. Forrester, M. J. Hay, and R. H. Thomson, ' Organic Chemistry of Stable Free Radicals,' Academic Press, London, 1967, ch. 5.

[14] O. Tsuge, M. Tashiro, and Y. Nishikara, *Tetrahedron Letters*, 1967, 3769.

[15] Y. Nomura, F. Furusaki, and Y. Takeuchi, *Bull. Chem. Soc. Japan*, 1970, **43**, 3002; 1967, **40**, 1740.

[16] M. J. Perkins, in ' Essays on Free Radical Chemistry,' Chem. Soc. Spec. Publ. No. 24, 1970, ch. 5.

[17] A. Mackor, Th. A. J. W. Wajer, Th. J. de Boer and J. D. W. Voorst, *Tetrahedron Letters*, 1967, 385.

Hence, in the B–K radical the 5-methyl group must have the negative and the 4-methylene the positive splitting. At this stage we were still uncertain whether the protons of the 4-methylene group were equivalent since accurate integration of the relatively broad n.m.r. signals which characterise radical spectra is not possible. Accordingly we calculated the e.s.r. spectra which would result from the coupling constants shown in the Table for the B–K radical with three couplings of −0.34 G and (a) one, (b) two, and (c) three couplings of +0.41 G. The resulting spectra are compared with the actual spectrum in Figure 1. The excellent fit for the spectrum with a_H +0.41 (2H) dispels any doubts about the equivalence of the methylene protons and further confirms our conclusion that coupling with the 3-methyl groups does not contribute to the hyperfine pattern.

Hyperfine coupling constants * (G) of the Banfield and Kenyon and related nitroxides

Nitroxide	Solvent	a_N	$a_{o,p\text{-H}}$	$a_{m\text{-H}}$	$a_{5\text{-alkyl}}$	$a_{4\text{-H}}$	$a_{\text{other H}}$
B—K nitroxide (6a)	CCl_4	12.15	2.33	0.85			
	$CDCl_3$			+0.889	−0.34	+0.41	
(8)	2,5-Me_2THF	11.5	2.48	0.87	*ca.* 0.46	*ca.* 0.46	
	C_6H_6	11.4	2.47	0.86	*ca.* 0.43	*ca.* 0.43	
(6; $R^1 = R^3 = Ph$, $R^2 = H$, $R^4 = Me$)	CCl_4	11.6	2.38	0.85		*ca.* 0.29	
	$CDCl_3$					+0.165	
	$Bu^t_2NO\cdot$			+0.865		+0.171	
(6; $R^1 = R^3 = H$,	CCl_4	11.15	2.72	0.90			$a_{2\text{-H}}$ 1.50
$R^2 = Et$, $R^3 = Pr$)	$Bu^t_2NO\cdot$			+0.94		+0.104	
(6; $R^1 = Me$, $R^2 = R^3 = H$,	CCl_4	12.0	2.32	0.81	*ca.* 0.40	*ca.* 0.40	
$R^4 = Ph$)							
(6; $R^1 = Pr^i$, $R^2 = R^3 = H$,	CCl_4	11.6	2.38				
$R^4 = Ph$)	$CDCl_3$			+0.765	−0.306	+0.223	$a^{Pr^i}_{CH_3}$ +0.223
(6; $R^1 = R^3 = Ph$, $R^2 = R^4 = H$)	CCl_4	10.95	2.48	0.85			
	$R_2NO\cdot$†			+0.86		+0.107	
(6; $R^1 = Et$, $R^2 = Me$, $R^3 = H$,	CCl_4	11.95	2.44	0.80			
$R^4 = Ph$)	$CDCl_3$			+0.855	−0.375	+0.127	$a^{Et}_{CH_3}$ +0.214
(7; R = PhNO) isomer a	CCl_4	11.6	2.38	0.94	0.50	1.03	
	$CDCl_3$			+0.87	−0.52	+0.115	
					and +0.115 or +0.950	or +0.950	
isomer b	CCl_4	11.8	2.31	0.94	0.42	0.89	
	$R_2NO\cdot$†			+0.85	−0.380	+0.176	
					and +0.176 or +0.804	or +0.804	

* Values with signs obtained by n.m.r. measurements at 100 or 220 MHz. † $R_2NO\cdot$ = 2,2,5,5-Tetramethyloxazolidine *N*-oxyl.

The B–K radical and several of its analogues provide rare but not unique [18,19] examples of radicals with two sets of β-protons whose coupling constants differ in sign. The coupling constants of β-protons of nitroxides with freely rotating alkyl groups are normally negative.[20] This is usually attributed [18] to spin polarisation of the bonds linking the nitrogen and the hydrogen and/or by hyperconjugative interaction of the unpaired electron on nitrogen with the electrons of the C_α–C_β bond the resulting spin on C_β being transmitted to the adjacent hydrogen atom by spin polarisation (Figure 2). Thus, the negative value for the 5-methyl protons of the B–K radical can be accounted for in this way. β-Protons with positive coupling constants suggest that the dominant process of spin transmission to them is homohyperconjugation [21] (Figure 2). Such interaction would be expected to be angular dependent and hence, our initial surprise that the 4-methylene protons of the B–K radical appeared to be equivalent, and desire for confirmation by spectral simulation. Also noteworthy is the non-equivalence of the β-methylene protons of the diastereoisomers of the nitroxide (7; R = PhNO) again confirmed by spectral simulation. This difference implies an angular dependence for the spin transmission process(es) leading to negative coupling constants. The nitroxide (6; $R^1 = Et$, $R^2 = Me$, $R^3 = H$, $R^4 =$ Ph) gave, in addition to n.m.r. signals attributable to β-protons, an additional relatively intense (*ca.* 3 H) signal downfield from tetramethylsilane. This we have assigned to the methyl protons of the 5-substituent. Also, for the nitroxide (6; $R^1 = Pr^i$, $R^2 = R^3 = H$, $R^4 = Ph$), the downfield signal corresponding to *a* +0.223 G was much too intense to be due only to the 4-methylene group. Therefore, we have assumed that the signals due to the 4-methylene group overlap that of the methyl protons of the isopropyl group. However, both of these assignments are only tentative since individual diastereoisomers could not be obtained, and e.s.r. spectra of the mixtures depended on the initial crystallisation procedure. This, and uncertainties in the multiplicity of minor splittings resulted in only approximate spectral simulations being achieved using the parameters given in the Table. Although the protons of the methyl groups in (6; $R^1 = Pr^i$, $R^2 = R^3 = H$, $R^4 = Ph$ and $R^1 = Et$, $R^2 = Me$, $R^3 = H$, $R^4 = Ph$) would be expected to have positive splittings, using a spin polarisation model, their values are much larger than would be expected.

From the foregoing discussion it is clearly difficult to

[18] A. Rassat and J. Ronzaud, *J. Amer. Chem. Soc.*, 1971, **93**, 5041; A. Rassat and P. Rey, *Tetrahedron*, 1973, **29**, 2845.

[19] R. M. Dupeyre, A. Rassat, and J. Ronzaud, *J. Amer. Chem. Soc.*, 1974, **96**, 6559.

[20] A. R. Forrester, S. P. Hepburn, and G. McConnachie, *J.C.S. Perkin I*, 1974, 2213 and references therein.

[21] G. A. Russell, G. Holland, K. Y. Chang, and L. H. Zalkow, *Tetrahedron Letters*, 1967, 1955; G. R. Underwood and V. L. Vogel, *J. Amer. Chem. Soc.*, 1971, **93**, 1058.

predict the coupling constants of β-protons, the sign and magnitude of which depend critically on their

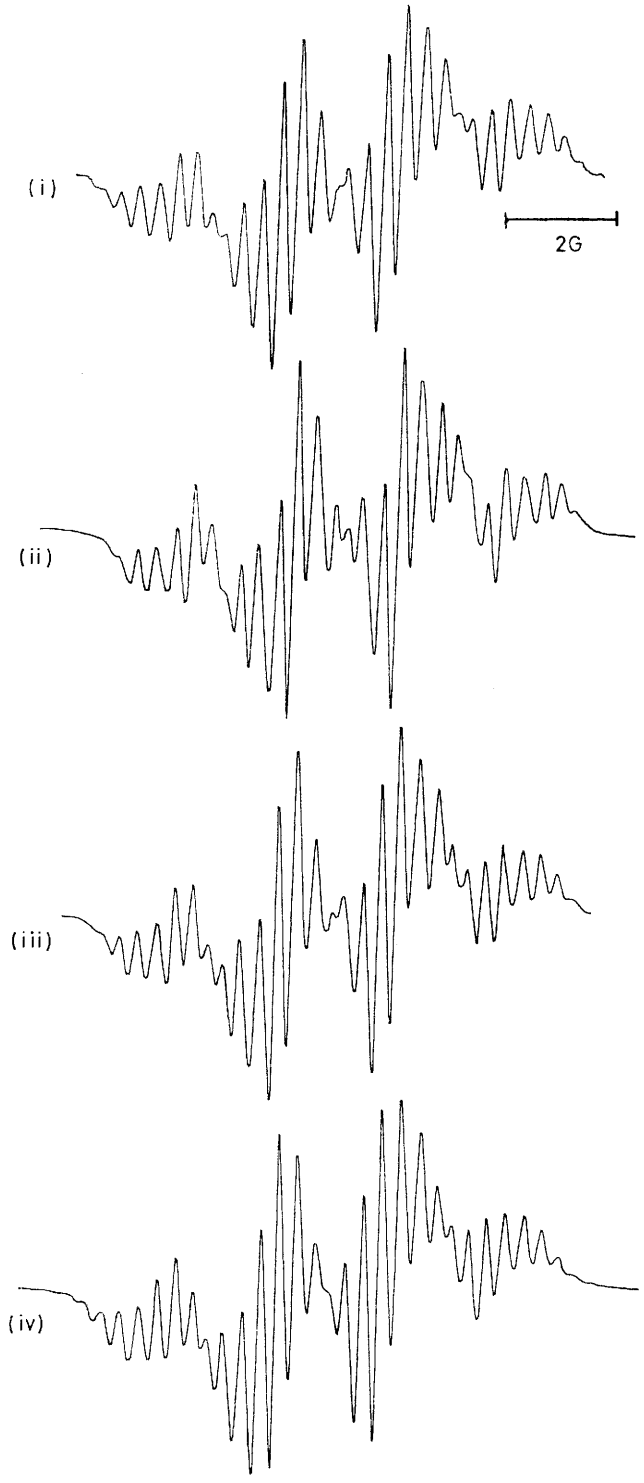

FIGURE 1 Actual (i) and simulated e.s.r. spectra of the B–K nitroxide (6a) (one component of nitrogen triplet) with (ii) one, (iii) two, and (iv) three couplings of 0.41 G

spatial disposition. Semi-empirical methods [22] are unreliable,[18] especially for systems in which free rotation of the bonds is not possible, and necessitate gross assumptions of bond angles. MO methods are difficult to apply to radicals as large and as complex as the B–K radical analogues and require a somewhat arbitrary choice [18] of parameters especially for nitrogen and oxygen. At present the only two generalisations which would appear to apply are (i) that the β-protons in freely rotating groups have small negative coupling constants and (ii) relatively large positive coupling constants are most likely to be found for β-protons in radicals of fixed or nearly-fixed geometry where the N–O and C_β–H bands are coplanar [23] (W rule).

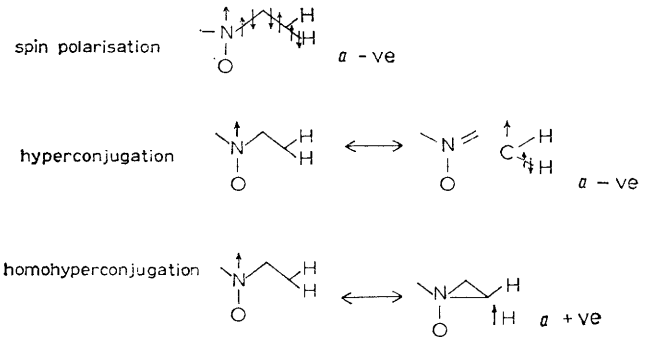

FIGURE 2 Spin transmission processes to β-hydrogens in nitroxides

EXPERIMENTAL

Spectra were measured in ethanol (u.v.), Nujol (i.r.), or deuteriochloroform (n.m.r.) unless stated otherwise. Petrol refers to light petroleum, b.p. 30—40°.

Preparation of Hydroxy(phenyl)aminoisoxazolidines.—5-[Hydroxy(phenyl)amino]-3,3,5-trimethyl-2-phenylisoxazolidine[5] (5; $R^1 = R^3 = R^4 = Me$, $R^2 = H$) and 5-[hydroxy(phenyl)amino]-4-ethyl-2-phenyl-3-propylisoxazolidine [12] (5; $R^1 = R^4 = H$, $R^2 = Et$, $R^3 = Pr$) were prepared by literature methods.

(i) 5-[*Hydroxy(phenyl)amino*]-3-*methyl*-2,3,5-*triphenylisoxazolidine* (5; $R^1 = R^3 = Ph$, $R^2 = H$, $R^4 = Me$). Acetophenone hydrazone (8.9 g, 66 mmol) in ether (200 ml) was shaken with yellow mercury(II) oxide (35 g), sodium sulphate (15 g), and a saturated solution of potassium hydroxide in ethanol (5 ml) for 2.5 h. The reaction mixture was filtered into a cold solution of nitrosobenzene (6.4 g, 60 mmol) in benzene (40 ml). Removal of the solvent *in vacuo* left an oil, treatment of which with petrol gave *methyl phenyl* N-*phenylnitrone* (11.5 g, 91%), m.p. 85—86.5° (from ether–petrol) (Found: C, 79.6; H, 6.1; N, 6.7. $C_{14}H_{13}NO$ requires C, 79.6; H, 6.2; N, 6.6%), $\lambda_{max.}$ 288 nm (log ε 3.54), δ 2.65 (3 H, s, Me), 7.10 (5 H, m, ArH), and 7.22 (5 H, m, ArH).

Saturated solutions of this nitrone in ether slowly (weeks) deposited crystals of the *isoxazolidine*, m.p. 138—139° (from petrol–ether) (Found: C, 79.3; H, 6.3; N, 6.7. $C_{28}H_{26}N_2O_2$ requires C, 79.6; H, 2.6; N, 6.6%), $\nu_{max.}$ 3 200 cm^{-1} (OH), δ (*ca.* 5 : 1 mixture of isomers a and b) 1.34[a] (3 H, s, Me), 1.52[b] (3 H, s, Me), 2.95[a] (1 H, d, *J* 13.3 Hz, 4-H), 3.10[b] (1 H, d, *J* 14.0 Hz, 4-H), 3.58[b] (1 H, d, *J* 14.0 Hz, 4-H), 3.92[a] (1 H, d, *J* 13.3 Hz, 4-H), 6.25[b] (1 H, s, OH), 6.45[a]

[22] Z. Luz, *J. Chem. Phys.*, 1968, **48**, 4186; M. Barfield, *J. Phys. Chem.*, 1970, **74**, 621.
[23] Y. Ellinger, A. Rassat, R. Subra, and G. Berthier, *J. Amer. Chem. Soc.*, 1973, **95**, 2372.

(1 H, s, OH), and 6.7—7.7[a,b] (20 H, m, ArH), *m/e* 422 (M^+ absent), 295 (63%), 211 (14), 208 (50), 193 (22), 192 (16), 191 (18), 180 (21), 165 (11), 109 (20), 106 (22), 105 (40), 103 (18), 90 (100), 77 (89), 65 (17), and 51 (16).

(ii) 5-[*Hydroxy*(*phenyl*)*amino*]-5-*methyl*-2,3-*diphenylisoxazolidine* (5; R^1 = Me, R^2 = R^3 = H, R^4 = Ph). To a solution of phenyl *N*-phenylnitrone [24] (4.0 g, 20 mmol), morpholine (2.2 g, 25 mmol) and toluene-*p*-sulphonic acid in benzene (60 ml), acetone (1.84 ml, 25 mmol) was added and the mixture was refluxed under a Dean–Stark water separator for 3.5 h. After removal of solvent the residual brown oil was chromatographed on silica gel (75 g, 5% water) using ether–petrol (1 : 4) as eluant to give the *isoxazolidine* (2.42 g), m.p. 112—114° (from ether–petrol or from methanol–dichloromethane at low temperature) (Found: C, 76.4; H, 6.8; N, 7.8%; M^+, 346.1683. $C_{22}H_{22}N_2O_2$ requires C, 76.3; H, 6.4; N, 8.1%; *M*, 346.1681), $\nu_{max.}$ 3 160 cm^{-1} (OH), δ (1 : 1 mixture of isomers a and b) 1.40 (3 H, s, Me), 1.51 (3 H, s, Me), 2.30[a] (1 H, dd, *J* 9.6 and 13.0 Hz, 4-H), 2.70[b] (1 H, dd, *J* 8.8 and 13.0 Hz, 4-H), 3.22[a,b] (2 H, dd, *J ca.* 8.0 and 13.0 Hz, 4-H), 4.44[b] (1 H, t, *J* 8.8 Hz, 3-H), 4.91[a] (1 H, dd, *J* 8.0 and 9.6 Hz, 3-H), 5.96 (1 H, s, OH), 6.65 (1 H, s, OH), and 6.7—7.5 (30 H, m, ArH) (assignments made after spin decoupling) *m/e* 346 (M^+) (0.8%), 238 (18), 182 (32), 181 (18), 180 (18), 118 (16), 91 (55), 77 (100), and 51 (18).

(iii) 6-[*Hydroxy*(*phenyl*)*amino*]-8,9-*diphenyl*-8-*aza*-7-*oxabicylo*[4.3.0]*nonane* (7; R = PhNOH) (*cf. ref.* 14). A solution of 1-morpholinocyclohexene [25] (3.3 g, 20 mmol), benzaldehyde (2.1 g, 20 mmol), and an excess of phenylhydroxylamine in benzene (40 ml) was heated at 60–70° under nitrogen for 16 h. The solvent was removed and the residue was chromatographed on silica gel (75 g, 5% water) with ether–petrol (1 : 9—3 : 7) as eluant to give the crude product as a yellow oil. Crystallisation from ether–petrol gave the isoxazolidine (isomer a) (950 mg), m.p. 126—128° (lit.,[14] 133—134°) (Found: C, 77.7; H, 7.0; N, 7.4%; M^+, 386.1994. Calc. for $C_{25}H_{26}N_2O_2$: C, 77.7; H, 6.8; N, 7.3%; *M*, 386.1994), $\nu_{max.}$ 3 420 cm^{-1} (OH), δ 0.8—2.3 (2 H, m, CH_2), 1.3–2.0 (5 H, m, CH_2), 2.4br (1 H, d, *J*, 11 Hz, 2′ or 5′-H), 3.02 (1 H, dt, J_d 11, J_t 6 Hz, 1-H), 5.21 (1 H, s, OH), 5.51 (1 H, d, *J* 6 Hz, 9-H), and 6.70—6.50 (15 H, m, ArH), *m/e* 386 (M^+) (0.5%), 278 (18), 198 (14), 189 (11), 182 (50), 180 (14), 91 (100), 77 (79), and 51 (22). Evaporation of the mother liquor followed by successive crystallisations of the residue from methanol and petrol gave the isoxazolidine (isomer b) (4.04 g), m.p. 123—124° (lit.,[14] 124—124.5°) (Found: C, 77.5; H, 7.1; N, 7.2%; M^+, 386.1994. Calc. for $C_{25}H_{26}N_2O_2$: C, 77.7; H, 6.8; N, 7.3%; *M*, 386.1994), $\nu_{max.}$ 3 440 and 3 200 cm^{-1} (OH), δ 1.30—2.10 (8 H, m, $4CH_2$), 3.25 (1 H, dt, J_d 7.6, J_t 4.8 Hz, 1-H), 4.37 (1 H, d, *J* 7.6 Hz, 9-H), 5.48 (1 H, m, OH), and 6.7—7.6 (15 H, m, ArH), *m/e* 386 (M^+) (0.8%), 278 (20), 182 (75), 180 (22), 173 (14), 130 (13), 91 (100), 77 (79), and 51 (18).

(iv) 5-[*Hydroxy*(*phenyl*)*amino*]-2,3-*diphenyl*-5-*isopropylisoxazolidine* (5; R^1 = Pr^i, R^2 = R^3 = H, R^4 = Ph). A solution of 3-methyl-2-morpholinobut-1-ene [26] (3.25 g, 21 mmol) and phenyl *N*-phenylnitrone (4.1 g, 21 mmol) in benzene (40 ml) was heated at 60—70° under nitrogen for 16 h. Work-up as in (iii) gave an oil, crystallisation of which from methanol at −78° gave the isoxazolidine (mainly isomer a) (177 mg), m.p. 156—160° (decomp.), δ 1.03 (6 H, d, *J* 6.8 Hz, 2Me), 2.49 (1 H, sept, *J* 6.8 Hz, CH), 2.86 (1 H, dd, *J* 4.0, 18 Hz, 4-H), 3.53 (1 H, dd, *J* 9.6, 18 Hz, 4-H), 5.15 (1 H, s, OH), 5.71 (1 H, dd, *J* 4.0, 9.6 Hz, 3-H), and 6.6—7.4 (15 H, m, ArH). Chromatography of the residue from the mother liquor on silica gel (75 g, 5% water) with ether–petrol (1 : 4) yielded an oil crystallisation of which from petrol gave the *isoxazolidine* (mainly isomer b) (1.25 g), m.p. 110—118° (Found: C, 77.2; H, 7.3; N, 7.6%; M^+, 374.1994. $C_{24}H_{26}N_2O_2$ requires C, 77.0; H, 7.0; N, 7.5%; *M*, 374.1994), $\nu_{max.}$ 3 240 cm^{-1} (OH), δ 1.10 (6 H, d, *J* 6 Hz, 2 Me), 2.15 (1 H, m, CH), 2.7—3.3 (2 H, m, 4-H), 4.18 (1 H, t, *J* 8.0 Hz, 3-H), and 6.8—7.6 (16 H, m, ArH, OH) (spectrum broadened owing to traces of nitroxide), *m/e* 374 (M^+) (1.5%) 267 (35), 266 (50), 250 (10), 196 (16), 182 (94), 181 (35), 180 (40), 146 (10), 104 (28), 91 (32), 77 (100), 71 (22), 51 (25), and 43 (45).

(v) 5-[*Hydroxy*(*phenyl*)*amino*]-5-*ethyl*-4-*methyl*-2,3-*diphenylisoxazolidine* (5; R^1 = Et, R_2 = Me, R^3 = H, R^4 = Ph). A solution of 3-morpholinopent-2-ene [27] (2.4 g, 15.6 mmol), phenyl *N*-phenylnitrone (3.4 g, 17 mmol), and phenylhydroxylamine (1.6 g, 15 mmol) in benzene (30 ml) was treated as in (iv). Chromatography of the crude product on silica gel with ether–petrol (1 : 5) produced an orange oil (5.4 g), crystallisation of which from petrol gave the *isoxazolidine* (1.84 g), m.p. 129.5—132° (Found: C, 77.1; H, 7.0%; N, 7.3%; M^+, 374.1994. $C_{24}H_{26}N_2O_2$ requires C, 77.0; H, 7.0; N, 7.5%; *M*, 374.1994), $\nu_{max.}$ 3 140 cm^{-1} (OH), δ (*ca.* 1 : 1 mixture of isomers a and b) 1.04[b] (3 H, d, *J* 7 Hz, 4-Me), 1.05[a] (3 H, t, *J* 7.0 Hz, $MeCH_2$), 1.07[b] (3 H, t, *J* 7.5 Hz, $MeCH_2$), 1.31[a] (3 H, d, *J* 7 Hz, 4-Me), 1.66[b] (2 H, q, *J* 7 Hz, CH_2Me), 1.89[a] (2 H, q, *J* 7.5 Hz, CH_2Me), 2.82[a] (1 H, dq, J_d 10.5, J_q 7 Hz, 4-H), 3.28[b] (1 H, dq, J_d 10, J_q 7 Hz, 4-H), 3.82[b] (1 H, d, *J* 10 Hz, 3-H), 4.48[a] (1 H, d, *J* 10.5 Hz, 3-H), 5.21[a] (1 H, s, OH), 5.99[b] (1 H, s, OH), and 6.8—7.6[a,b] (15 H, s, ArH) (assignments based mainly on spin decoupling), *m/e* 374 (M^+) (0.3%), 266 (22), 210 (22), 198 (11), 182 (45), 181 (18), 180 (13), 132 (20), 104 (16), 91 (71), 77 (100), 57 (45), 51 (25).

(vi) 5-[*Hydroxy*(*phenyl*)*amino*]-2,3,5-*triphenylisoxazolidine* (5; R^1 = R^3 = Ph, R^2 = R^4 = H). A solution of α-morpholinostyrene (3.8 g, 20 mmol) and phenyl *N*-phenylnitrone (4.0 g, 20 mmol) after reaction as in (iv) gave a red oil which was chromatographed on silica gel with ether–petrol (1 : 9—3 : 7) to give the *isoxazolidine* (1.52 g), m.p. 120.5—122° (from dichloromethane–methanol at −35°) (Found: C, 79.5; H, 6.0; N, 7.1. $C_{27}H_{24}N_2O_2$ requires C, 79.4; H, 5.9; N, 6.9%), $\nu_{max.}$ 3 250 cm^{-1} (OH), δ (*ca.* 2 : 3 mixture of isomers a and b) 2.82[b] (1 H, dd, *J* 10 and 13.5 Hz, 4-H), 3.16[a] (1 H, t, *J* 8.5 Hz, 4-H), 3.68[a,b] (1 H, m, 4-H), 4.46[a] (1 H, t, *J* 8.5 Hz, 3-H), 4.82[b] (1 H, m, 3-H), 5.99 (1 H, s, OH), 6.55 (1 H, s, OH), and 6.9–7.5[a,b] (40 H, m, ArH) (assignments based mainly on spin decoupling), *m/e* 408 (M^+ absent), 211 (4%), 195 (8), 181 (10), 180 (32), 105 (9), 91 (100), 77 (60), 64 (6), and 51 (18).

N.m.r. Measurements on Nitroxides.—The hydroxylamines (1 mmol) in dichloromethane (30 ml) were shaken with silver oxide (0.75 mmol) until the solution no longer gave a red colour with alkaline triphenyltetrazolium chloride.[28] After removal of silver residues the filtrate

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was evaporated below room temperature to give the nitroxides. These were dissolved in the minimum quantity (0.3—0.5 ml) of solvent (carbon tetrachloride, deuteriochloroform, di-t-butyl nitroxide,[29] or 2,2,5,5-tetramethyloxazolidine *N*-oxyl [30]) and n.m.r. spectra measured on Varian HR-220 or HA100 spectrometers with a sweep-width 20 kHz upfield and downfield from tetramethylsilane and 10—15 kHz modulation.

The B–K nitroxide, m.p. 87—89° (lit.,[5] 88—90°), (3-methyl-2,3,5-triphenylisoxazolidin-5-yl) phenyl nitroxide, m.p. 89—90°, and (8,9-diphenyl-8-aza-7-oxabicyclo[4.3.0]-nonan-6-yl) phenyl nitroxide, m.p. 114—116 and 105.5—107° (isomers a and b, respectively), formed relatively stable orange or red crystals while the others were oils which decomposed at room temperature.

Spin Trapping.—In separate experiments (a) 2,5-dimethyltetrahydrofuran, (b) 2-methyl-2,3-dihydrobenzofuran,[31] and (c) 2,3,5-triphenylisoxazolidine [32] in benzene (1 : 1—1 : 3) or neat was treated with di-t-butyl peroxide (3—6 drops) and nitrosobenzene (small crystal) and the mixture thoroughly degassed. Irradiation of the resulting solutions in the cavity of an E3 Varian e.s.r. spectrometer was effected using a 100 W high pressure mercury vapour lamp. In an alternative procedure, 2,5-dimethyltetrahydrofuran, containing a little nitrosobenzene, was shaken with nickel peroxide and the spectrum of the radical measured as before.

Other Experiments.—(i) A solution of 8,9-diphenyl-6-pyrrolidin-1-yl-8-aza-7-oxabicyclo[4.3.0]nonane [15] (1.75 g, 5 mmol) and phenylhydroxylamine (0.55 g, 5 mmol) in benzene was heated under reflux for 4 days and left at room temperature for 3 weeks. Work-up yielded only the starting isoxazolidine (1.57 g).

(ii) No significant reaction occurred when a solution of the above isoxazolidine (348 mg, 1 mmol) and phenyl *N*-phenylnitrone (197 mg, 1 mmol) in benzene was heated at 70° for 5 days. Addition of toluene-*p*-sulphonic acid and further heating produced only decomposition products of the starting materials.

(iii) In separate experiments methyl phenyl *N*-phenylnitrone (422 mg, 2 mmol) was treated with (a) diphenyl *N*-phenylnitrone (2.73 g, 10 mmol) and phenylhydroxylamine (10 mg) in chloroform (20 ml), (b) phenyl *N*-phenylnitrone (985 mg, 5 mmol) and phenylhydroxylamine (10 mg) in chloroform (10 ml), and (c) diphenyl *N*-phenylnitrone (546 mg, 2 mmol) in ethanolic sodium ethoxide [from sodium (50 mg) and ethanol (60 ml)]. The reaction mixtures after standing for several weeks gave (a) mainly the diphenyl *N*-phenylnitrone (b) and (c) several unidentified products none of which gave a positive hydroxylamine test with 2,3,5-triphenyltetrazolium chloride.[28]

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