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STABLE NITROXIDE RADICALS FROM PHENYLISATOGEN AND ARYLIMINO-DERIVATIVES WITH ORGANO-METALLIC COMPOUNDS

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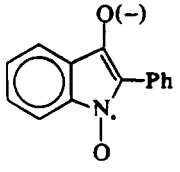
Abstract—Stable nitroxide radicals were obtained by the oxidation of 1-hydroxyindolines prepared by allowing the organo-metallic compounds to act upon 2-phenylisatogen and arylimino-derivatives. In both cases nitroxides are obtained with a^N of approximately 9 gauss, in agreement with similar known compounds. The ESR spectra of numerous nitroxide radicals are discussed and a number of cases of magnetic non-equivalence of methylenic protons adjacent to asymmetric carbon are brought to light.

In previous work[1] it has been shown that when phenylisatogen and 2 - phenyl - 3 - aryliminoindolenine - N - oxides are reduced by potassium t-butylate/DMSO[2] they afford the corresponding nitroxide radical anions **1** and **2** with a coupling constant $a^N = 5{\cdot}7$–$6{\cdot}0$ gauss. Neutral nitroxide radicals **3** and **4**, the a^N of which is not dissimilar, were, however, obtained from the oxidation of 1 - hydroxy - 2 - phenyl - 3 - arylamino derivatives with PbO_2. The present paper deals with the indolinic nitroxide radicals **5** and **6**, which have a coupling constant $a^N = 9{\cdot}2$–$9{\cdot}8$ gauss and which are obtained from the action of the organo-metallic compounds upon phenylisatogen **7** and 3-arylimino-derivatives **12** and subsequent oxidation by exposure to the air or with PbO_2.

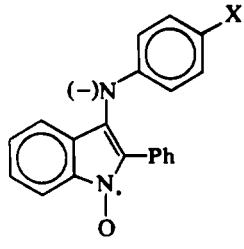
The reaction of phenylisatogen **7** with phenylmagnesium bromide had previously been studied by Ruggli *et al.*[3] using an organo-metallic compound/phenylisatogen molar ratio of 4:1; they attributed structure **9** to the isolated product, but this was in marked contrast with the properties of the product itself, which was insoluble in alkalis and could be neither acylated nor oxidated. We repeated the reaction using a molar ratio of 1·2:1† and were able to show that phenylisatogen behaves as a bidentate system, reacting both at carbonyl and at the N=C double bond. The compounds obtained were the alcohols **8**, as main products, and the hydroxylamines **9** in low yield (Scheme 1).

The structure of the products **8**, which cannot be oxidated and are insoluble in alkalis, is in agreement with the analytical and spectroscopic data (Table 1), namely, the absence in the IR spectrum of bands due to CO and the presence of an OH band; in the NMR spectrum there is a signal at about 8·5 δ, corresponding to two hydrogens, characteristic of the grouping $-\underset{\displaystyle O}{\overset{\displaystyle |}{N{=}C}}-C_6H_5$, and due to the

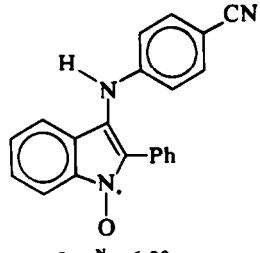
†Using a molar ratio 4/1, like Ruggli, we obtained similar results with much lower yields, particularly in the case of compounds **9**.



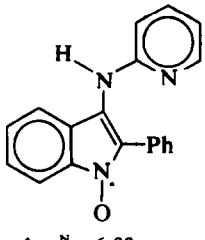
1: $a^N = 5{\cdot}6$ gauss



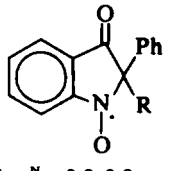
2: $a^N = 5{\cdot}7$–$5{\cdot}9$ gauss



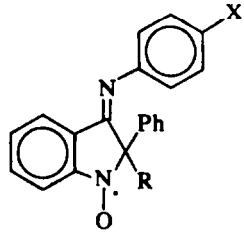
3: $a^N = 6{\cdot}00$ gauss



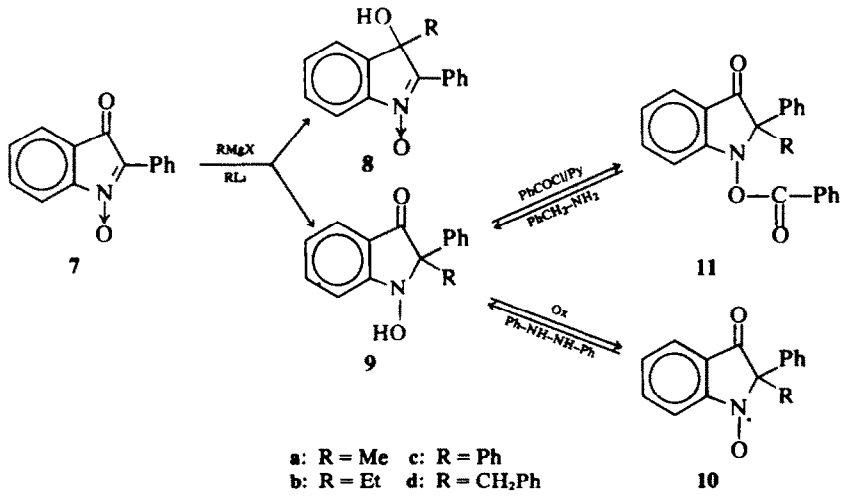
4: $a^N = 6{\cdot}00$ gauss



5: $a^N = 9{\cdot}2$–$9{\cdot}8$ gauss



6: $a^N = 9{\cdot}3$–$9{\cdot}7$ gauss



Scheme 1

two *ortho* hydrogens of the phenyl.* We believe that structure **8** should be assigned to the product isolated by Ruggli, for there is a certain correlation in the m.p., which is the only finding in the literature.

The structure assigned to product **9** is in agreement with the chemical properties and spectroscopic data (Table 2). These compounds are soluble in 10% NaOH and can be benzoylated to give the compounds **11**, from which they can then be regenerated by aminolysis with benzylamine. Furthermore, the hydroxylamines **9** are easily oxidised by PbO_2 or by exposure to the air to give the nitroxide radicals **10**, from which they can be recovered in quantitative yield by reduction with hydrazo-benzene. The ESR spectra and structure of these radicals will be discussed below. Finally, the structure of compounds **9** is borne out by the fact that they were obtained from the compounds **13** on hydrolysis (see below).

When using lithio-organic compounds in the place of Grignard reagents we obtained practically the same results. Only in the case of phenyl lithium it was possible to record the ESR spectrum of another radical (in addition to that of the nitroxide **10c**) with a coupling constant $a^N = 13{\cdot}15$ gauss; however, the latter product was obtained in too low a yield to enable a more detailed study to be carried out.

We then studied the action of the organo-metallic compounds upon the arylimino-derivatives **12** and, in the case of both Mg and Li derivatives, obtained exclusively and with good results the corresponding N-hydroxy-compounds **13** (Scheme 2).

The structure of these compounds agrees with their chemical properties and spectroscopic data (Table 3); they can be benzoylated to give compounds **16**, from which they can be regenerated by aminolysis with benzylamine. Furthermore, the derivatives **13** are very easily oxidized in the nitroxide radicals **14**, from which they can be recovered by reduction with hydrazobenzene; finally, acid hydrolysis of the latter affords not only the amines **15** but also the ketones **9**, some of which were previously obtained from 2-phenylisatogen.

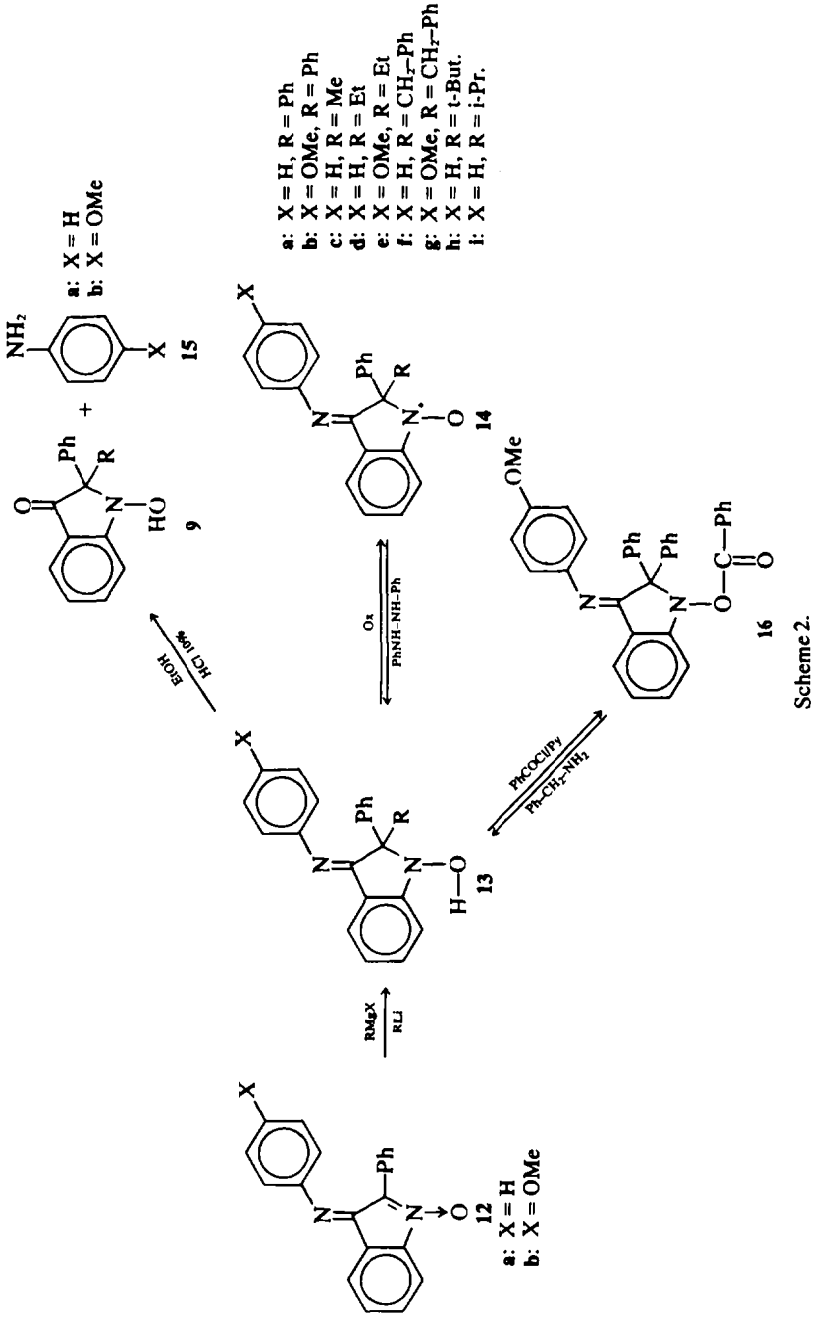
The nitroxide radicals **10** and **14** are intensely-red crystalline compounds. Table 4 sets out their analytical, physical and spectroscopic data. In the IR spectra of these compounds no signal occurs in the OH region, which points to a high percentage of radical; indeed, when this percentage was determined by comparison with 2,2,6,6 - tetramethyl - 4 - piperidinol - 1 - oxyl† (TANOL) our compounds were found to be 100% radical (in benzene at room temp.), not dimerizing to any appreciable extent in solution at concentrations of up to 10^{-2} molar. Absolute determination of the percentage of radical in the solid state, carried out using Gouy's magnetic balance method, confirmed this finding. Furthermore, radicals **10** and **14** are perfectly stable in the solid state and can be kept without any particular precautions. Benzene solutions of these radicals, kept in vacuum-sealed test-tubes, have the same intensity of signal after five months.

Discussion of the spectra. Radicals **10** and **14** exhibit generally well-resolved ESR spectra (Figs. 1a, 2), interpretation of which enabled the structure to be determined. They all have a 1:1:1 nitrogen triplet and a coupling constant $a^N = 9{\cdot}2$–$9{\cdot}8$ gauss. This value is incompatible with an indolic structure,[1,4] in which nitrogen would have a coupling constant of 5–6 gauss; rather, it agrees with values given in the literature for radicals with an indolinic structure,[5] which structure is confirmed in the case of our radicals by examination of the IR spectra, for in each case there is a band at about 1600 cm^{-1}, characteristic of the grouping $-\overset{|}{\underset{|}{C}}-N-Ph$, in which carbon does not have double bonds.[6]

The ESR spectra of the indolinone-derived radicals **10** are quite simple and exhibit the interaction of the unpaired electron not only with a N atom but also with two pairs of hydrogens, having $a^H = 3$ and $a^H = 1$ gauss.

*The same signal at approx. 8·5 δ is observed in the NMR spectrum of 2-phenylisatogen and in various other cases in which the same grouping is present (unpublished findings). Structure **8** also takes into account the shift to a higher field (0·24 δ) of the signal of the CH_2–CH_3 group in the NMR spectrum of **8b**, for, as is clear from the molecular model, in this case the CH_3 group falls exactly above the pentatomic ring and is thefore shielded by it.

†In the course of these determinations we found that DPPH is not an apt reference standard for the measurement of the percentages of radical, for it itself if only approx. 80% radical (in benzene solution at room temperature). Repeated crystallisations of DPPH following the methods described in the literature (A. R. Forrester, J. M. Hay and R. H. Thomson, *Organic Chemistry of Stable Free Radicals*, p. 138 Academic Press, New York 1968), did not bring about any appreciable increase in the percentage of radical.


a: X = H
b: X = OMe
15
9
a: X = H, R = Ph
b: X = OMe, R = Ph
c: X = H, R = Me
d: X = H, R = Et
e: X = OMe, R = Et
f: X = H, R = CH2-Ph
g: X = OMe, R = CH2-Ph
h: X = H, R = t-But.
i: X = H, R = i-Pr.
14
Ox
PhNH-NH-Ph
EtOH
HCl 10%
13
PhCOCl/Py
Ph-CH2-NH2
16
RMgX
RLi
12
a: X = H
b: X = OMe

Scheme 2.

Table 1. Analytical and spectroscopic data of compounds **8a–d**

Compound	m.p.°C	Solvent	Formula	Analysis	found % calcd %		IR(ν) cm^{-1}	NMR(δ)
8a	246	acetic ac/ /lig.	$C_{15}H_{13}NO_2$	C 75·83 75·30	H 5·56 5·48	N 5·94 5·85	3140*	1·6 (3H, s, CH_3); 4·82 (1H, broad, OH); 6·7–7·6 (7H, m, aromatic); 8·55 (2H, m aromatic).
8b	220	aceton/ p. ether	$C_{16}H_{15}NO_2$	C 76·35 76·87	H 5·90 5·97	N 5·63 5·53	3160*	0·24 (3H, t, $CH_2\underline{CH_3}$); 2·2 (2H, m, $\underline{CH_2}CH_3$); 5·2 (1H, broad, OH); 6·6–7·7 (7H, m, arom.); 8·53 (2H, m, arom.).
8c	252	acetic ac.	$C_{20}H_{15}NO_2$	C 80·24 79·72	H 4·96 5·10	N 4·91 4·65	3150*	4·87 (1H, broad, OH); 7·2–8·2 (12H, m, arom.); 9·38 (2H, m, arom.).†
8d	200	aceton/ p. ether	$C_{21}H_{17}NO_2$	C 79·82 79·98	H 5·43 5·43	N 4·70 4·44	3160*	3·32 (2H, m, $-\underline{CH_2}Ph$); 5·4 (1H, s, OH); 6·18–7·47 (16 H, m, arom.); 8·52 (2H, m, arom.).

*broad.
†in C_5D_5N.

Table 2. Analytical and spectroscopic data of compounds 9a–d

Compound	m.p.°C	Formula	Analysis	found %	calcd %		IR(ν) cm^{-1}	NMR (δ)
9a	129	$C_{15}H_{13}NO_2$	C 75·51	H 5·74	N 5·96		1610[a]–1685[b]	1·51 (3H, s, CH_3); 5·7 (1H, broad,
			75·29	5·48	5·86		3300[c]	OH); 6·8–7·9 (9H, m, arom.)
9b	164	$C_{16}H_{15}NO_2$	C 76·16	H 5·95	N 5·96		1610[a]–1678[b]	0·78 (3H, t, CH_2CH_3); 2·42 (2H, m,
			75·87	5·97	5·53		3300[c]	CH_2CH_3); 5·3 (1H, broad, OH);
								6·7–7·8 (9H, m, arom.).
9c	145	$C_{20}H_{15}NO_2$	C 80·18	H 4·91	N 4·87		1615[a]–1690[b]	5·3 (1H, broad, OH); 6·8–7·9 (14H,
			79·71	5·02	4·65		3300[c]	m, arom.)
9d	150	$C_{21}H_{17}NO_2$	C 80·52	H 5·37	N 4·59		1610[a]–1680[b]	3·78 (2H, broad, CH_2Ph); 5·3
			79·98	5·44	4·44		3300[c]	(1H, broad, OH); 6·7–7·8 (14H, m,
								arom.).

a, ν (Ph–N–C–); *b*, ν (C=O); *c*, ν (–OH).

Table 3. Analytical and spectroscopic data of compounds 13a–l

Compound	m.p.°C	Formula	Analysis	Found %	calcd %		IR(ν) cm^{-1}	NMR(δ)
13a	171	$C_{26}H_{20}N_2O$	C 82·93	H 5·32	N 7·52		1600[a]	5·7 (1H, broad, OH); 7·2–8·2 (19H,
			82·95	5·36	7·44		1650[b]	m, arom.)
							3160[c]	
13b	184	$C_{27}H_{22}N_2O$	C 79·63	H 5·60	N 6·67		1600[a]	3·8 (3H, s, CH_3); 5·8 (1H, broad, OH);
			79·78	5·46	6·89		1645[b]	7·2–8·2 (18H, m, arom.).
							3230[c]	
13c	180	$C_{21}H_{16}N_2O$	C 80·26	H 5·73	N 8·91		1600[a]	1·9 (3H, s, CH_3); 5·7 (1H, broad, OH);
			80·23	5·77	9·11		1650[b]	6·5–7·8 (14H, m, arom.).
							3230[c]	
13d	160	$C_{22}H_{20}N_2O$	C 80·36	H 6·02	N 8·48		1600[a]	0·9 (3H, t, $-CH_2CH_3$); 2·55 (2H, q,
			80·46	6·14	8·53		1650[b]	CH_2CH_3); 4·2 (1H, broad, OH);
							3240[c]	6·5–7·8 (14H, m, arom.).
13e	190	$C_{23}H_{22}N_2O_2$	C 77·30	H 6·25	N 8·03		1600[a]	0·95 (3H, t, CH_2CH_3); 2·57 (2H, q, CH_2CH_3);
			77·07	6·19	7·81		1650[b]	3·88 (3H, s, OCH_3); 5·2 (1H, broad, OH);
							3200[c]	6·5–7·5 (13H, m, arom.).
13f	183	$C_{27}H_{22}N_2O$	C 83·15	H 5·66	N 7·33		1600[a]	3·92 (2H, m, CH_2Ph); 3·95 (1H, broad,
			83·05	5·68	7·17		1650[b]	OH); 6·8–7·8 (19H, m, arom.).
							3160[c]	
13g	171	$C_{28}H_{24}N_2O_2$	C 79·66	H 5·94	N 6·83		1600[a]	3·84 (3H, s, OCH_3); 3·87 (2H, m, CH_2Ph);
			79·98	5·75	6·66		1640[b]	5·85 (1H, broad, OH); 6·8–7·8 (18H, m,
							3160[c]	arom.).
13h	not isolated							
13l	175	$C_{23}H_{22}N_2O$	C 81·52	H 6·48	N 8·69		1600[a]	1·1 [6H, m, $CH(CH_3)_2$]; 3·2 [1H, m, $CH(CH_3)_2$];
			80·67	6·48	8·18		1640[b]	5·4 (1H, broad, OH); 6·8–7·8 (14H, m,
							3160[c]	arom.).

a, ν (Ph–N–C–); *b*, ν (>C=N–Ar); *c*, ν (–OH)

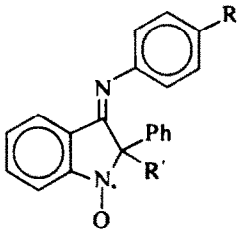
Spin-density calculations, according to MacLachlan, revealed that in these radicals the greater coupling constant is to be assigned to the hydrogens bonded to carbons C5 and C7 (*ortho* and *para*, respectively, to nitrogen) and the lesser to the C4 and C6 hydrogens (*meta* to nitrogen) of the indolinonic ring. The ESR spectrum of the radical **10c** exhibits no other couplings, while that of **10a** also exhibits an interaction of the unpaired electron with the three hydrogens of methyl bonded to C2 in the ring ($a^H = 0·12$ gauss). The spectra of the radicals **10b** and **10d** are more interesting in that they exhibit an even number of lines. This points to the interaction of the unpaired electron with an odd number of equivalent hydrogens, which can only be explained if it is admitted that, for purposes of the ESR spectrum, the two hydrogens of the CH_2 groups bonded to the C2 of the indolinonic ring are not equivalent. Confirmation of this non-equivalence was furnished by the NMR spectra of the corresponding hydroxylamines (Fig. 3): in the case of **9b** the NMR signal of CH_2 is not a quartet but, as might be expected for an ABC_3[7] system, somewhat more complex; in the case of **9d**, however, the CH_2 signal is rather broadened, but resisted efforts to resolve it. When the ESR and NMR spectra are recorded at temperatures ranging from −30° to +110° there is no variation either in the shape of the spectra or in the value of the coupling constants, which would suggest that the non-equivalence could hardly be due to a hindrance of rotation around the C2/CH_2R bond, particularly as no such hindrance is observed in the molecular models. We believe, therefore, that the non-equivalence in question is due to the presence of chiral carbon (the C2 of the ring) bonded to

Table 4. Analytical and spectroscopic data of compounds **10a-d** and **14a-i**

Compound	m.p.°C	Formula	Analysis	Found % / calcd %		IR(ν) cm⁻¹
10a	167	$C_{15}H_{12}NO_2$	C 75·61	H 5·97	N 6·18	1580[a]
			75·90	5·07	5·88	1720[b]
10b	115	$C_{16}H_{14}NO_2$	C 76·13	H 5·79	N 5·29	1580[a]
			76·16	5·59	5·55	1720[b]
10c	128	$C_{20}H_{14}NO_2$	C 80·22	H 4·71	N 5·04	1575[a]
			79·98	4·70	4·67	1730[b]
10d	not isolated					
14a	195	$C_{26}H_{19}N_2O$	C 83·01	H 5·19	N 7·46	1590[a]
			83·17	5·10	7·68	1660[c]
14b	165	$C_{27}H_{21}N_2O_2$	C 80·13	H 5·30	N 6·88	1600[a]
			79·98	5·22	6·91	1650[c]
14c	originated in solution by oxidation of **12c**					
14d	147	$C_{22}H_{19}N_2O$	C 81·17	H 6·05	N 8·51	1595[a]
			80·71	5·81	8·56	1660[c]
14e	112	$C_{23}H_{17}N_2O_2$	C 78·44	H 4·73	N 8·01	1610[a]
			78·17	4·85	7·93	1660[c]
14f	162	$C_{27}H_{21}N_2O$	C 82·95	H 5·38	N 7·29	1590[a]
			83·28	5·43	7·19	1650[c]
14g	175	$C_{28}H_{23}N_2O_2$	C 80·21	H 5·49	N 6·92	1605[a]
			80·17	5·52	6·68	1650[c]
14h	131	$C_{24}H_{23}N_2O$	C 81·67	H 6·56	N 7·88	1590[a]
			81·09	6·52	8·19	1655[c]
14i	155	$C_{23}H_{21}N_2O$	C 81·10	H 6·09	N 8·48	1595[a]
			80·91	6·20	8·20	1655[c]

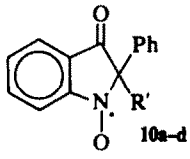
a, ν(Ph–N–C–); *b*, ν(>C=O); *c*, ν(>C=N–Ar).

Table 5.* ESR data



14a–i

Compound	R	R'	a^{N_1}	$a^{H_{o,p}}$	a^{H_m}	a^{N_2}	$a^{R'}$
14a	H	Ph	9·36	3·13	1·00	0·75	—
14b	OMe	Ph	9·36	3·13	1·00	0·75	—
14c	H	Me	9·52	3·20	1·00	0·75	0·12 (3H)
14d	H	Et	9·32	3·28	1·08	0·78	0·25 (1H)
14e	OMe	Et	9·35	3·21	1·08	0·79	0·29 (1H)
14f	H	CH_2Ph	9·38	3·21	1·04	0·70	0·50 (1H); 0·05 (1H)
14g	OMe	CH_2Ph	9·38	3·21	1·04	0·70	0·50 (1H); 0·05 (1H)
14h	H	t-Bu	9·61	3·10	1·10	0·75	<0·05 (9H)
14i	H	i-Pr	9·60	3·13	1·10	0·78	<0·05 (7H)



10a–d

Compound	R'	a^N	$a^{H_{o,p}}$	a^{H_m}	$a^{R'}$
10a	Me	9·58	3·15	1·05	0·12 (3H)
10b	Et	9·52	3·09	1·01	0·29 (1H)
10c	Ph	9·50	3·04	1·01	—
10d	CH_2Ph	9·21	3·04	1·00	0·50 (1H); 0·05 (1H)

*The values of *a* were measured in C_6H_6 or CCl_4 solution. In $CHCl_3$ solution the observed values of a^N were 0·3–0·4 gauss higher, according to Lemaire and Rassat.[16]

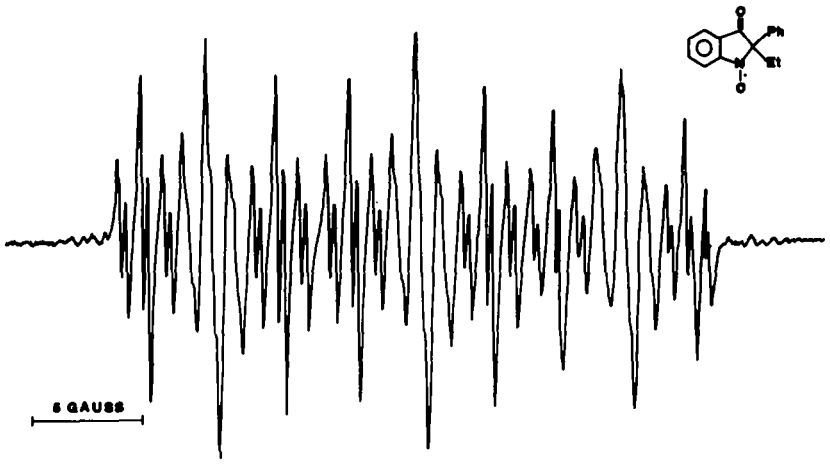


Fig. 1a. ESR first-derivative spectrum of the nitroxide **10b**: observed spectrum, in chloroform solution.

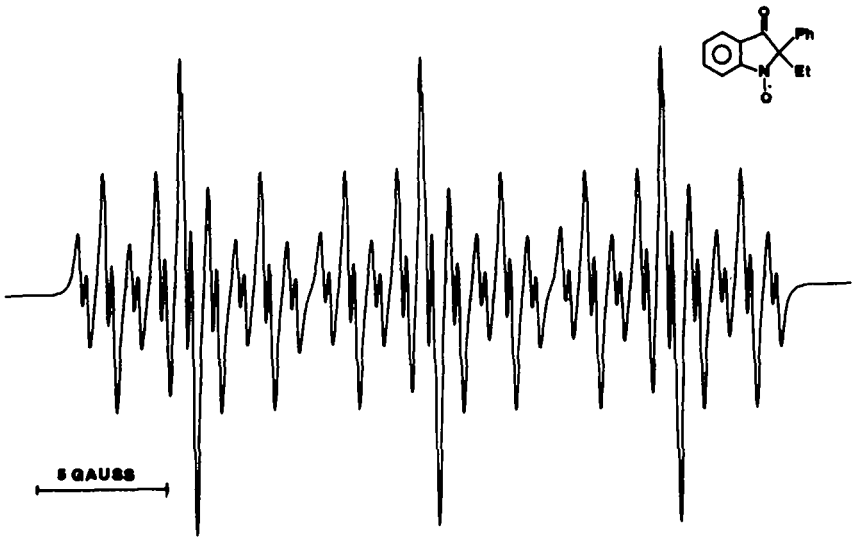


Fig. 1b. Calculated spectrum of the nitroxide **10b** with Lorentzian line width of 0·25 gauss.

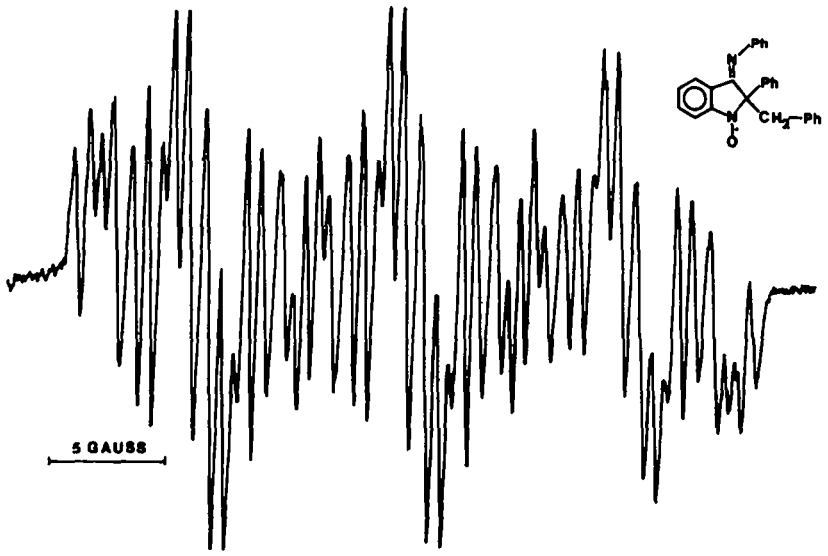


Fig. 2. ESR first-derivative spectrum of the nitroxide **14b** in chloroform solution.

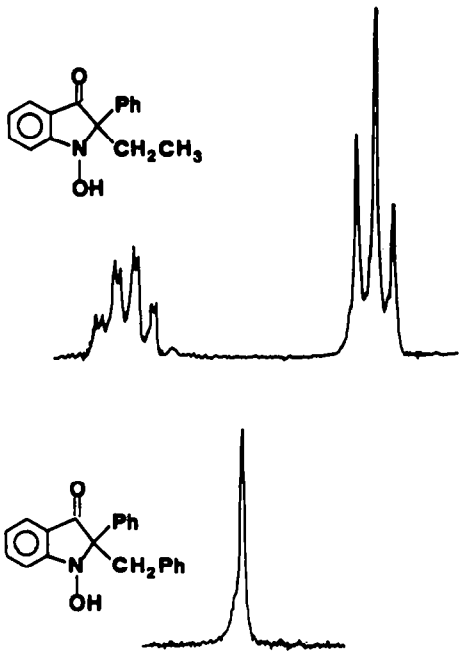


Fig. 3. NMR spectra of the hydroxylamines **9b** (top) and **9d** (bottom) (only the aliphatic hydrogens region is shown).

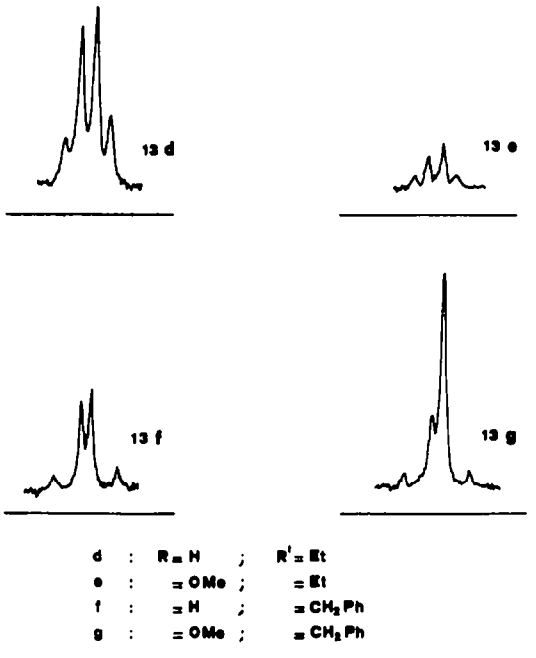


Fig. 4. NMR spectra of the hydroxylamines **13d-g** (only the CH_2 region is shown).

CH_2. Examples of this type of chirality in NMR spectroscopy are well known,[8] while in the field of ESR spectroscopy few examples have been described[9] and they refer to hydrogens beta to the radical centre, that is to structures of the type $-\dot{N}-CH_2-CXYZ$. In our case, the non-equivalence involves two diastereotopic hydrogens *gamma* to the radical centre and *beta* to the chiral centre, that is of the type $-\dot{N}-CXY-CH_2-R$. In our case, in view of the greater distance from the radical centre, the ESR coupling-constant values are naturally much smaller; we were able to measure both constants in the case of **9d** ($a^H = 0{\cdot}50$ and $0{\cdot}05$ gauss) but only one in the case of **9b** ($a^H = 0{\cdot}29$ gauss).

The ESR spectra of the radical **14**, deriving from the 3-aryliminoindolinones are somewhat more complex than those of the radicals **10** because of the presence of an additional N atom, but it proved possible to interpret them nevertheless. The values of the different coupling constants are set out in Table 5. Here too, in addition to endocyclic nitrogen having $a^H = 9{\cdot}3$–$9{\cdot}8$ gauss, there are two pairs of hydrogens, with $a^H = 3$ and 1 gauss, which, on the basis of a spin-density calculation according to MacLachlan, were again attributed to hydrogens 5–7 and 4–6, respectively. A further small coupling constant ($0{\cdot}70$–$0{\cdot}79$ gauss) can be attributed to exocyclic nitrogen. Finally, ESR spectroscopy of the radicals **14a**, **14e**, **14f**, **14g** shows that the diastereotopic protons of the CH_2–R group bonded to the C2 of the indolinonic ring are not equivalent either (Table 5). Here again, this non-equivalence is confirmed by the NMR spectra (Fig. 4); in the case of the hydroxylamines **13f** and **13g** the CH_2 signal is a quartet that can clearly be referred to an AB* system, whereas for **13d** and **13e** the CH_2–CH_3 group gives a simple, somewhat broadened, quartet that we were not able to resolve.

Finally, the coupling constant values obtained from the spectra and set out in the Tables were confirmed in all cases by means of reconstruction of the experimental spectra with the calculation. Figure 1b shows the reconstruction of the spectrum of compound **10b**, but in each case the agreement between experimental and calculated spectra was satisfactory.

*In the case of **13g** the singlet of the OCH_3 group is superimposed on the quartet of the CH_2 group, but the spectrum is nevertheless easy to interpret.

EXPERIMENTAL

The m.ps were not corrected. The IR spectra were recorded in nujol using a Perkin-Elmer 257 apparatus; the NMR spectra were recorded in $CDCl_3$ on a Perkin-Elmer R 12 B using TMS as internal standard; the ESR spectra were recorded in $CHCl_3$ on 10^{-3} M solutions using a Varian E4 apparatus. Absolute determination of the percentage of radical was performed using a magnetic balance from Newport Instruments. Gas-chromatography was performed with a Carlo Erba Fractovap GV using columns of SE30 silicone.

2-Phenylisatogen[10] and 1 - oxide - 2 - phenyl - 3 - aryliminoindolenines[11] were prepared as described in the literature. The Grignard reagents were prepared according to the usual methods in N_2 atmosphere and in THF, except in the case of MeMgI in which ether was used. The organo-lithium compounds (Fluka) were generally used in benzene and in N_2 atmosphere.

(A) *2-Phenylisatogen with Grignard reagents.* 6 mM of Grignard reagent were added dropwise, at room temp. and in a current of N_2 to 5 mM of 2 - phenyl - isatogen in 60 ml of THF. After being shaken for 2 hr the mixture was poured into a 5% NH_4Cl aq. and extracted with $CHCl_3$. The chloroform extract was dehydrated and evaporated to dryness and the resultant residue recovered with benzene; the benzene soln thus obtained was chromatographed on silica using benzene as the eluent. The eluates yielded traces of phenylisatogen and of nitroxide radicals **10a–d** (of which only **10a** was isolated in any quantity), which were identified by means of their ESR spectra. Extraction of the column with acetone afforded the products **8a–d** in 50–60% yield; the relevant analytical and spectroscopic data are set out in Table 1.

(B) *2-Phenylisatogen with organo-lithium compounds* (LiR: R=Me, Et, Ph). Organo-lithium compound (3 mM) was added to 2·5 mM of 2-phenylisatogen in 50 ml benzene dropwise, at room

temp. and in a stream of N_2. After being shaken for 2 hr the mixture was washed as described above. Washing the residue of the chloroform layer with ether or ligroin-acetone afforded the products **8a–d** in 20–30% yield. When the solvents were evaporated to dryness they gave a residue which, on being chromatographed on SiO_2 with benzene, in turn yielded a fraction corresponding to the nitroxide radicals **10a–c**, which were identified by means of their ESR spectra performed on the chloroform extraction solution. In the case of the reaction with LiPh to the radical **10c** a yellowish-orange fraction was obtained, the chloroform extraction soln of which afforded an ESR spectrum with a triplet due to nitrogen and with a coupling constant $a^N = 13{\cdot}15$ gauss. The yield of the product was too low to enable more detailed studies to be carried out.

(C) 1 - *Oxide* - 2 - *phenyl* - 3 - *arylimino indolenines* **12a–b** *with Grignard reagents and organo-lithium compounds.* Grignard reagent (2 mM) was added dropwise, at room temp. and in a stream of N_2 to 1 mM of arylimino indolenine-N-oxide in 100 ml of THF. After 2–3 hr the mixture was washed with NH_4Cl aq and extracted with $CHCl_3$. On evaporation, dehydration and subsequent evaporation to dryness the chloroform extract yielded a residue which, when recovered with benzene and a little light petroleum, in turn afforded, in some cases, **13a–d** (in yields of 80%, 85%, 50% and 60%, respectively) invariably accompanied by the corresponding radicals **14a–d**. Generally speaking, it proved simpler to dissolve the residue of the chloroform extract in benzene and oxidise it with PbO_2 at room temp. The soln was filtered off from the PbO_2 in reduced volume and then chromatographed on SiO_2 with benzene to give the nitroxide radicals **14a–i**, which were purified by EtOH (yields 50–85%). The nitroxide **14c** was only obtained in soln. The analytical and spectroscopic data are set out in Table 4. The same results were obtained with the organolithium compounds: reactions were conducted in anhyd benzene at room temp. and in a N_2 atm, using an excess of 20% of organo-lithium compound.

(D) *Hydroxylamino derivatives* **13a–i** *by reduction of the nitroxides* **14a–i** *with hydrazobenzene.* Radicals **13a–i** (1 mM) in the minimum quantity of $CHCl_3$ were reduced with 0·6 mM hydrazobenzene. At room temp. the reaction was immediate, the colour changing instantaneously from red to yellow. When the soln thus obtained was heated to b.p. and ligroin was added the hydroxylamines **13a–i** were obtained in almost quantitative yield. Chromatography of the solvent yielded azobenzene. Further purification was carried out by crystallisation from $CHCl_3$/ligroin or benzene/ligroin; relative spectroscopic and analytical data are set out in Table 3. The product **13h** was not isolated owing to difficulties of purification.

(E) *Hydrolysis of the hydroxylamines* **13b, c, d, f.** Hydroxylamino derivative (5 mM) and 10 ml 5% HCl in 60 ml EtOH were refluxed for 1 hr. The mixture was evaporated to dryness and recovered with $CHCl_3$ and dil. $NaHCO_3$. The chloroform extract was evaporated and dehydrated. This soln, which gas chromatography showed to contain aniline or *p*-anisidine, was treated with PbO_2. After 1 hr the soln was separated from the PbO_2, evaporated to dryness, recovered with benzene and chromatographed on silica with benzene eluent. The nitroxide radicals **10a–d** were isolated and purified from EtOH (70–80% yields). The hydroxylamine **9d** was obtained directly from the product **13f** by chromatography of the mixture on SiO_2 with benzene before oxidation with PbO_2. The analytical and spectroscopic data referring to **9a–d** are set out in Table 2 and those referring to **10a–d** are set out in Table 4.

(F) *Hydroxylamines* **9a–c** *by reduction of the nitroxide radicals* **10a–c** *with hydrazobenzene.* The hydroxylamines **9a–c** were obtained in almost quantitative yield from 5 mM nitroxide radicals **10a–c** and 2·7 mM hydrazobenzene following the technique described in parag. D, above. The products were purified from benzene/light petrolether. The relevant analytical and spectroscopic data are set out in Table 2.

(G) *Benzoylation of* **9c** *and* **13b.** Hydroxylamine **9c** (3 mM) in the minimum quantity of pyridine was treated with 2 ml PhCOCl at room temp. The mixture was left to stand for 2 hr and then water was added under shaking until **11** had precipitated fully. This product was purified from benzene/petrolether m.p. 165° (quantitative yields); IR nujol: ν (C=O) 1725 cm^{-1}; ν (OCOPh) 1750 cm^{-1}; NMR ($CDCl_3$): 7·2–8 δ (m, arom.). (Found: C, 80·45; H, 4·67; N, 3·81. Calcd for $C_{27}H_{19}NO_3$: C, 79·98; H, 4·72; N, 3·46%).

The benzoyl derivative **16** was obtained from **13b** following the same technique, m.p. 147° from benzene/petrolether; IR (nujol) ν (>C=N–Ar) 1660 cm^{-1}, ν (OCOPh) 1760 cm^{-1}; NMR ($CDCl_3$) 3·86 δ (CH_3, s), 6·6–7·8 δ (23 H, arom.). (Found: C, 80·46; H, 5·06; N, 6·10. Calcd. for $C_{34}H_{26}N_2O_3$: C, 79·98; H, 5·13; N, 5·49%).

(H) *Reaction of aminolysis on products* **11** *and* **16.** Compounds **11** and **16** (5 mM) and 5 mM $PhCH_2NH_2$ in the minimum quantity of benzene were left to stand for 4 days. Chromatography of the soln on SiO_2 with benzene eluent afforded **9c** and **13b** on elution and benzoylbenzylamine on extraction of the column with acetone.

(I) *Assessment of the percentage of radical.* The percentage of radical was determined by comparing the ESR signals of benzene solns approx. 10^{-3} M of the radicals **10** and **14** with the ESR signals of benzene solns approx. 10^{-3} M of 2,2,6,6 - tetramethyl - 4 - piperidinol - 1 - oxyl. Double integration of the signal was done numerically, according to Wyard,[13] and the radical content proved to be 100% with a relative deviation of 1%.

(J) *Spin-density calculations.* Spin-density calculations were carried out according to MacLachlan,[14] a value of 1·2 being attributed to λ, with the help of an automatic calculation program. The following values, suggested by Figeys and Dedieu,[15a] were used for the parameters:

$$h_N = 1{\cdot}19 \qquad h_N = 0{\cdot}44 \qquad h_O = 0{\cdot}84$$

$$k_{C-N} = 1{\cdot}06 \qquad k_{C-C} = 1{\cdot}23 \qquad k_{C-N} = 1{\cdot}29$$

$$k_{N-O} = 1{\cdot}10$$

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REFERENCES

[1]P. Bruni and M. Colonna, *Tetrahedron* **29**, 2425 (1973).
[2]G. A. Russell, E. G. Janzen and E. T. Strom, *J. Am. Chem. Soc.* **86**, 180 (1964).
[3]P. Ruggli, B. Hegedüs and E. Caspar, *Helv. Chim. Acta* **22**, 411 (1939).
[4]A. R. Forrester, R. H. Thomsom and G. R. Luckurst, *J. Chem. Soc.* (B), 1311 (1968).
[5]C. Chapelet-Letourneux, H. Lemaire and A. Rassat, *Bull. Soc. Chim. Fr.* 3285 (1965); G. A. Russell, C. L. Myers, P. Bruni, F. A. Neugebauer and R. Blankespoor, *J. Am. Chem. Soc.* **92**, 2762 (1970).
[6]B. Witkop and J. B. Patrick, *Ibid.* **73**, 713 (1951).
[7]R. J. Abraham, *The Analysis of High Resolution NMR Spectra*, p. 185. Elsevier, Amsterdam (1971); F. Kaplan and J. D. Roberts, *J. Am. Chem. Soc.* **83**, 4666 (1961).
[8]M. L. Martin and G. J. Martin, *Bull. Soc. Chim. Fr.* 2117 (1966); M. Gorkom and G. E. Hell, *Quart. Revs* **22**, 14 (1968).
[9]B. C. Gilbert and M. Trenwith, *J. Chem. Soc.* (Perkin II), 1834 (1973); B. C. Gilbert, J. P. Larkin and R. O. C. Norman, *Ibid.* (Perkin II), 1272 (1972); E. Flesia, A. Croatto, P. Tordo and J. M. Surzur, *Tetrahedron Letters* 535 (1972); R. W. Kreilick, J. Becher and E. F. Ulman, *J. Am. Chem. Soc.* **91**, 5121 (1969); R. J. Weinkam and E. C. Jorgensen, *Ibid.*, **93**, 7028, 7033 (1971).
[10]F. Kröhnke and J. Vogt, *Chem. Ber.* **85**, 376 (1952).
[11]L. Marchetti, L. Greci and G. Tosi, *Gazz. Chim. Ital.* **100**, 770 (1970).
[12]H. Lemaire and A. Rassat, *J. Chim. Phys.* **61**, 1580 (1964).
[13]S. J. Wyard, *J. Sci. Instrum.* **42**, 769 (1965).
[14]A. D. MacLachlan, *Mol. Phys.* **3**, 233 (1960).
[15]H. P. Figeys and P. Dedieu, *Theoretica Chim. Acta* **9**, 82 (1967).

[a]The value $k_{N-O} = 1{\cdot}10$ (which is not found among those suggested by Figeys and Dedieu) was used for HMO calculations on nitroxides by R. Ramasseul, Thèse Grenoble 1968, No. 2559.