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Oxidative Dimerization of Quinolinic Nitroxides in the Presence of Trichloro- and Trifluoro- Acetic Acid. Crystal Structures of 6,6'-bis-(1-oxide-1,2,6,8a-tetrahydroquinoline)ylidene and of 2,3-Diphenylquinoline

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Abstract: Quinolinic nitroxides **1a-c** react with trichloro- (TCA) and trifluoro- (TFA) acetic acid to give dimers **3a-c** and quinolines **4a-c** as the main products. Products **3a-c** are explained as arising *via* the intermediate formation of the radical cation **5**, which forms the final dimer through an oxidative dimerization promoted by the TCA or TFA. The formation of products **4a-c** is explained by a Wagner-Meerwein type transposition of the phenyl group from C-2 to C-3. The disproportionation, which generally occurs in the presence of acid for nitroxides having the N-O function conjugated with a π-system, has been excluded even though quinoneimine N-oxides **2a-c** were isolated. The structure of compounds **3a** and **4a** were determined by crystal X-ray analysis.

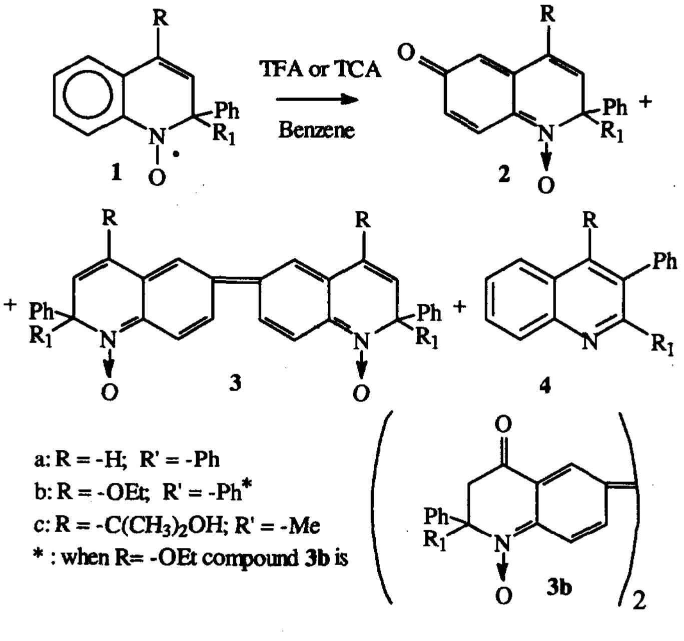
The use of nitroxide radicals in the last decade has received a great development in several fields for many applications. They are studied as "contrast agents" in MR-imaging,[1] used in pharmacological investigations[2] and more recently they have been proposed as superoxide dismutation mimics.[3] Nitroxides are used for studying membranes,[4] enzymes[5] and for oxygen determination (oxymetry).[6] Some of them are used or generated *in situ via* radical trapping by suitable scavengers, mostly PBN (N-*tert*-butyl-α-phenylnitrone)[7] and DMPO (5,5-dimethyl-1-pyrroline-N-oxide), in particular media such as acidic solutions or complex biological systems.[8] Several derivatives of the tetramethyl-piperidine and -pyrrolidine are also used as probes for studying structural properties of polymers.[9] Consequently, the study of their behaviour in different conditions can be useful.

Most of the nitroxides used or generated have the unpaired electron localized in the nitroxide function and are structurally similar to the tetramethyl-piperidine,[10] -pyrrolidine[10] and imidazolyl series.[11] Instead, the indolinonic and the quinolinic nitroxides,[12] and their derivatives,[12] have the N-O group in a conjugated position with the π system of the benzenic ring of the indolic or the quinolinic nucleus and they possess a very high stability if compared to diaryl and alkyl-aryl-nitroxides.

Since we are developing the applications of the latter in biology,[13] in polymers[14] and in the study of reaction mechanisms on the basis of their reactivity,[15,16] in the present paper we report the study of some quinolinic nitroxides under acid treatment by TCA and TFA.

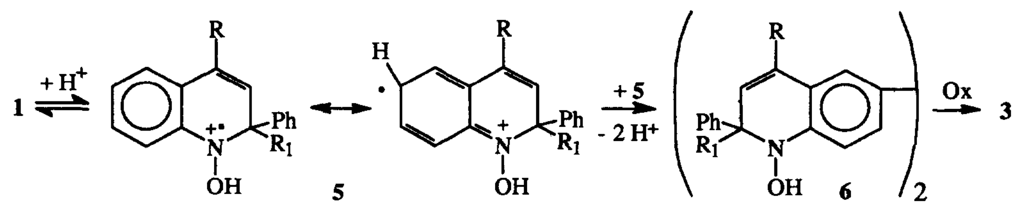
RESULTS

Quinolinic nitroxides **1a-c** when treated at room temperature for 10 minutes with a triple quantity of TCA or TFA in a benzene solution carefully degassed with nitrogen or argon, gave the dimers **3a-c** and the quinolines **4a-c**, as the main products, together with traces of quinoneimine N-oxides **2a-c** (Scheme 1).



Scheme 1

The structures of dimers **3a-c** were identified by X-ray analysis of **3a** and by comparing their spectroscopic data, besides the fact that all these compounds give a deep violet solution. The ^{1}H-NMR spectra are poorly resolved: compound **3a** gave a non legible spectra whereas compounds **3b** and **3c** show a structure very similar to that of the quinoneimine N-oxide. The IR spectrum of compound **3b** shows the band of the carbonyl group at C-4 (1730 cm^{-1}), that of compound **3c**, the band of the OH group at 3377 cm^{-1} (Table 3). Compounds **4a-c** were identified by X-ray analysis of **4a**, and by comparing their spectroscopic data (Table 3). The ^{1}H-NMR spectra show characteristic signals between 7.2 and 8.7 ppm due to the hydrogen atoms attached to the benzenic ring, at 8.24 ppm due to the hydrogen at C-4 for **4a**, at 1.16 and 3.69 ppm due to the hydrogens of the substituent at C-4 for **4b** and at 1.64 ppm due to the hydrogens of the methyl groups of the *iso*-propanol substituent at C-4 for **4c**. Compound **4c** also shows at 2.3 ppm the signal for the hydrogens of the methyl group at C-2. Quinoneimine N-oxides **2a-c**, which were also obtained by oxidizing the nitroxides **1a-c** in acetonitrile/water with cerium ammonium nitrate (see experimental) were identified by their analytical and spectroscopic data.



Scheme 2

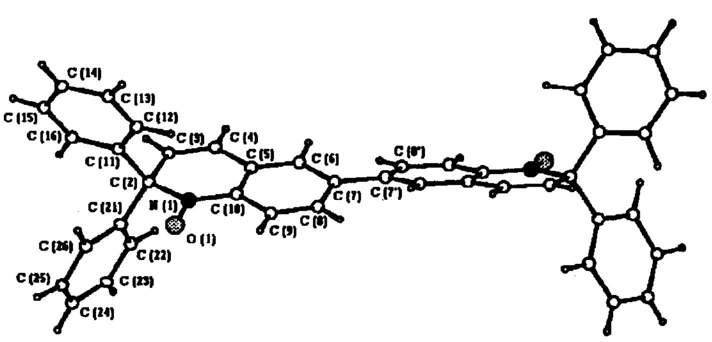


Fig. 1. Perspective view of 6,6'-bis-(1-oxide-1,2,6,8a-tetra-hydro-quinoline)-ylidene **3a**.

Their ^{1}H-NMR spectra show characteristic signals (see Table 3) in the region between 6.6 and 8.0 ppm, due to the hydrogens of the benzenic ring of the quinolinic moiety, and between 5.6 and 6.6 ppm due to the proton at C-3. Moreover compounds **2b** and **2c** also show the signals characteristic of the hydrogens of their substituents at C-4. The IR spectrum of compound **2c** shows the OH band at 3330 cm^{-1}. Amines **8a-c** (Scheme 4), which were prepared by refluxing nitroxides **1a-c** with Fe/AcOH, were identified by their analytical and spectroscopic data (Table 3). The ^{1}H-NMR spectra show characteristic signals between 6.5 and 7.8 ppm due to the hydrogens of the benzenic ring, at ca. 5.8-5.9 ppm due to the hydrogen at C-3 for **8a** and **8c**, at 3.38 ppm due to the peak of the two hydrogens at C-3 for **8b**, and at 1.6 ppm due to the hydrogens of the substituent at C-4 for **8c**. The IR spectra show the bands due to the NH at ca. 3200-3400 cm^{-1}, and for compound **8c** the OH band at 3560 cm^{-1}. All mass spectra gave the expected molecular ion peaks.

The reactions carried out with an excess of TFA gave the same products, in higher yields, whereas in the above conditions some starting nitroxide was recovered.

Molecular geometry

Figures 1 and 2 show a drawing of the molecule of compounds **3a** and **4a** with the arbitrary numbering scheme adopted in the crystallographic analysis; Table 1 lists bond distances and angles.*@

The conformational geometry of the molecule was deduced from the torsion angles of Table 1 and from the analysis of the planarity reported in Table 2.

For both compounds, bond distances and angles are mostly as expected from hybridization of the atoms. The main differences in the skeleton of the two-condensed six-membered rings concern bond distances and angles, according to the different hybridization of the carbon atom in position two, being sp^3 in compound **3a** and sp^2 in **4a**. Nevertheless the quinoline moiety adopts a conformation substantially planar in both compounds, being 1.3(1) and 0.4(1)° the values of the dihedral angles between the two mean planes of the six-membered rings in compounds **3a**

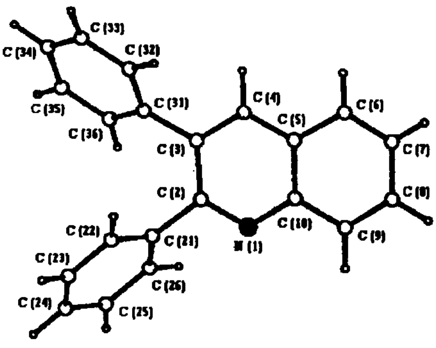


Fig. 2. Perspective view of 2,3-diphenyl-quinoline **4a**.

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* The atomic coordinates are available from the Director of the Cambridge Crystallographic Data Centre, University Chemical Laboratories, Lensfield Road, Cambridge CB2 1EW.
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,@ Supplementary data available: Atomic fractional coordinates, list of thermal parameters and structure factors.

and **4a**, respectively. In compound **4a** the geometry of the quinoline system is in good agreement with that found in similar molecules reported in literature,[17] slight differences in bond distances and angles being interpreted in terms of steric interactions of the two adjacent phenyl substituents.

Table 1. Bond Distances (Å), Angles (°) and Selected Torsion Angles(°) with e.s.d.'s in Parentheses.

	3a	4a
Bond Distancess (Å)		
O(1)-N(1)	1.282(4)	
N(1)-C(2)	1.506(4)	1.326(3)
N(1)-C(10)	1.373(5)	1.371(3)
C(2)-C(3)	1.505(6)	1.440(3)
C(2)-C(11)	1.528(6)	
C(2)-C(21)	1.536(6)	1.491(3)
C(3)-C(4)	1.327(6)	1.370(3)
C(3)-C(31)		1.491(3)
C(4)-C(5)	1.432(5)	1.403(3)
C(5)-C(6)	1.386(6)	1.414(3)
C(5)-C(10)	1.416(5)	1.419(3)
C(6)-C(7)	1.401(5)	1.365(4)
C(7)-C(8)	1.412(7)	1.401(5)
C(7)-C(7')	1.454(6)	
C(8)-C(9)	1.369(6)	1.364(3)
C(11)-C(12)	1.382(6)	
C(11)-C(16)	1.390(5)	
C(12)-C(13)	1.392(8)	
C(13)-C(14)	1.371(8)	
C(14)-C(15)	1.374(7)	
C(15)-C(16)	1.379(7)	
C(21)-C(22)	1.378(6)	1.384(4)
C(21)-C(26)	1.385(7)	1.382(4)
C(22)-C(23)	1.383(7)	1.393(4)
C(23)-C(24)	1.376(10)	1.374(5)
C(24)-C(25)	1.368(8)	1.374(5)
C(25)-C(26)	1.388(7)	1.385(4)
C(31)-C(32)	1.401(4)	
C(31)-C(36)	1.379(3)	
C(32)-C(33)	1.392(6)	

	3a	4a
C(33)-C(34)	1.368(6)	
C(34)-C(35)	1.379(5)	
C(35)-C(36)	1.396(4)	
Angles (°)		
O(1)-N(1)-C(2)	115.2(3)	
O(1)-N(1)-C(10)	120.0(3)	
C(2)-N(1)-C(10)	124.7(3)	119.2(3)
N(1)-C(2)-C(3)	109.9(3)	123.0(3)
N(1)-C(2)-C(11)	108.2(3)	
N(1)-C(2)-C(21)	106.6(3)	114.3(3)
C(3)-C(2)-C(11)	106.9(3)	
C(3)-C(2)-C(21)	111.7(3)	122.7(2)
C(11)-C(2)-C(21)	113.4(4)	
C(2)-C(3)-C(4)	124.9(4)	117.0(2)
C(2)-C(3)-C(31)		122.9(3)
C(4)-C(3)-C(31)		120.2(3)
C(3)-C(4)-C(5)	121.3(4)	121.8(3)
C(4)-C(5)-C(6)	122.8(3)	124.1(3)
C(4)-C(5)-C(10)	119.3(4)	117.5(2)
C(6)-C(5)-C(10)	117.9(4)	118.4(2)
C(5)-C(6)-C(7)	123.2(4)	120.5(3)
C(6)-C(7)-C(7')	122.8(4)	
C(6)-C(7)-C(8)	116.4(4)	120.8(3)
C(7')-C(7)-C(8)	120.8(4)	
C(7)-C(8)-C(9)	122.7(4)	120.6(3)
C(8)-C(9)-C(10)	119.3(4)	120.0(3)
N(1)-C(10)-C(5)	119.7(4)	121.6(2)
N(1)-C(10)-C(9)	119.8(4)	118.7(3)
C(5)-C(10)-C(9)	120.5(4)	119.7(3)
C(2)-C(11)-C(12)	121.8(4)	

	3a	4a
C(2)-C(11)-C(16)	119.4(4)	
C(12)-C(11)-C(16)	118.6(4)	
C(11)-C(12)-C(13)	120.1(5)	
C(12)-C(13)-C(14)	120.9(5)	
C(13)-C(14)-C(15)	119.1(6)	
C(14)-C(15)-C(16)	120.7(5)	
C(11)-C(16)-C(15)	120.6(4)	
C(2)-C(21)-C(22)	120.6(4)	121.2(2)
C(2)-C(21)-C(26)	120.7(4)	120.3(2)
C(22)-C(21)-C(26)	118.7(4)	118.5(3)
C(21)-C(22)-C(23)	121.3(5)	120.4(3)
C(22)-C(23)-C(24)	119.6(5)	120.2(3)
C(23)-C(24)-C(25)	119.7(6)	119.8(4)
C(24)-C(25)-C(26)	120.9(5)	119.9(3)
C(21)-C(26)-C(25)	119.8(4)	121.1(3)
C(3)-C(31)-C(32)		119.9(2)
C(3)-C(31)-C(36)		122.1(2)
C(32)-C(31)-C(36)		117.9(2)
C(31)-C(32)-C(33)		120.2(3)
C(32)-C(33)-C(34)		121.2(3)
C(33)-C(34)-C(35)		119.4(4)
C(34)-C(35)-C(36)		119.9(3)
C(31)-C(36)-C(35)		121.5(3)
Selected Torsion Angles(°)		
O(1)-N(1)-C(2)-C(11)	62.4(4)	
O(1)-N(1)-C(2)-C(21)	-60.0(4)	
N(1)-C(2)-C(3)-C(4)	2.7(6)	-2.0(5)
C(21)-C(2)-C(3)-C(31)		-5.8(5)
C(3)-C(2)-C(21)-C(22)		-61.7(5)
C(4)-C(3)-C(31)-C(32)	136.4(4)	

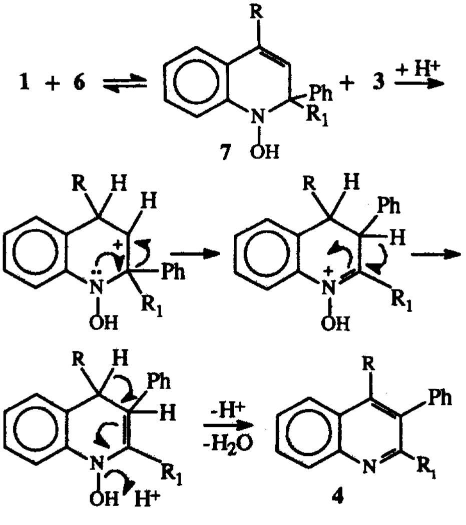
The crystal structure of **3a** consists of symmetric molecules for the presence of a two-fold crystallographic axis perpendicular to the C(7)-C(7') bond and inclined by 78.7° with respect to the mean planes of the two quinolinic rings. In this compound the geometry of the quinoline moiety is comparable to that found in the 1,2-dihydro-2,2-diphenyl-quinoline-1-oxyl previously studied;[18] also the orientation of the N-oxide group with respect to the quinoline ring is similar and in agreement with its more marked planar arrangement. In fact the oxygen atom is out of the C-N-C plane by 0.037(3) Å corresponding to an angle of 1.6(4)° (Table 2). The N-O bond length of 1.282(4) Å, which is intermediate between the values characteristic for N=O double bond, 1.20 Å, and N-O-R single bond, 1.44 Å,[19] is in agreement with that found for heterocycle N-oxides.[20]

Table 2. Analysis of the Planarity

	3a	4a		3a	4a		3a	4a
a) Distances ($\AA \times 10^3$) of relevant atoms from the mean plane with e.s.d.'s in parentheses: starred atoms were not used to define the plane.								
Plane *A*: N(1)C(2)C(3)C(4)C(5)C(10)			Plane *C*: C(11)-C(16)			Plane *E*: C(31)-C(36)		
N(1)	9(3)	3(3)	C(11)	10(4)		C(31)		2(4)
C(2)	-22(4)	-10(3)	C(12)	-7(4)		C(32)		-3(5)
C(3)	10(4)	8(3)	C(13)	-1(6)		C(33)		1(5)
C(4)	9(4)	0(3)	C(14)	4(6)		C(34)		2(5)
C(5)	-7(3)	-7(3)	C(15)	5(6)		C(35)		-2(5)
C(10)	0(4)	5(3)	C(16)	-11(4)		C(36)		0(5)
O(1)*	8(3)		C(2)*	-58(4)		C(3)*		-66(4)
C(21)*		-88(3)	Plane *D*: C(21)-C(26)			b) Angles (°) between planes		
C(31)*		78(3)	C(21)	-2(4)	1(4)	*A* - *B*	1.3(1)	0.4(1)
Plane *B*: C(5)-C(10)			C(22)	7(5)	9(4)	*A* - *C*	107.3(1)	
C(5)	9(3)	-1(3)	C(23)	-9(6)	-12(4)	*A* - *D*	105.0(1)	118.7(1)
C(6)	-2(4)	-2(4)	C(24)	-1(6)	3(4)	*A* - *E*		133.5(1)
C(7)	-9(3)	3(4)	C(25)	6(5)	9(4)	*C* - *D*	65.1(2)	
C(8)	11(3)	0(4)	C(26)	-3(5)	-9(4)	*D* - *E*		118.0(1)
C(9)	-5(4)	-2(3)	C(2)*	44(4)	-91(4)	*AB* - *A'B'*	157.4(1)	
C(10)	-17(4)	2(3)						

DISCUSSION

2,2,6,6-Tetramethylpiperidine-1-oxyl when treated with hydrochloric acid undergoes a disporportionation reaction forming the corresponding oxoammonium ion and hydroxylamine;[21] no data are reported with carboxylic acid. Diaryl- and arylalkyl- nitroxides undergo a spontaneous disproportionation to the corresponding quinoneimine-N-oxides and amines,[22] which is faster in the presence of carboxylic acids. Indolinonic nitroxides slowly afford to the corresponding amines and quinoneimine-N-oxides in the presence of TFA.[23]



Scheme 3

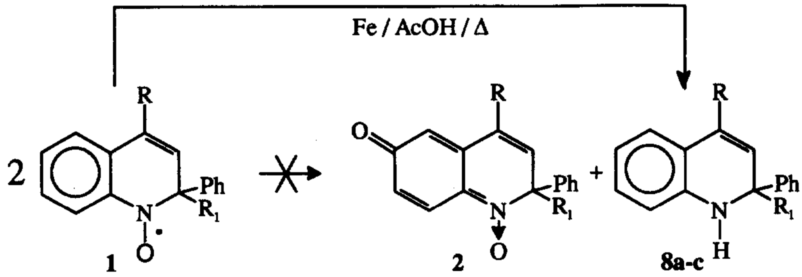
Nitroxides **1a-c**, which are perfectly stable in solution, are transformed by TCA or TFA treatment, into the corresponding dimers **3a-c** through a dimerization forming a carbon-carbon bond followed by an oxidative step. Dimerization involving only the nitroxide function was observed in the piperidino- and pyrrolidino-nitroxides series in particular conditions,[24] whereas spontaneous dimerization with formation of a carbon-carbon or carbon-oxygen bond was only observed with vinyl nitroxides.[25]

In our case, the dimerization could be explained as proceeding through coupling of two molecules of the radical cation of the nitroxide at C-6 followed by deprotonation of the intermediate, forming the N,N'-dihydroxy dimer **6** (Scheme 2). Since the reactions were carried out in the absence of oxygen, the last oxidative step in which the N,N'-dihydroxy dimer is transformed into **3**, is a complicated task. The possible candidate for oxidation could be the starting nitroxide which could act as hydrogen abstractor forming the hydroxylamine **7** in agreement with the equilibrium depicted in Scheme 3.

The fact that the hydroxylamine **7** corresponding to the nitroxide was never observed, could be due to its transformation to the quinoline **4**, through protonation, transposition of a phenyl group and elimination of water, as shown in Scheme 3. The transformation of **7** into **4** may also contribute to shift the equilibrium depicted in Scheme 3 to the right. Since the nitroxide **1c** is methyl and phenyl substituted at C-2, for compound **4c** the migration of the phenyl group, which in general occurs better than alkyl group could be expected. Thus, on this basis, established in the Wagner-Meerwein type transpositions study,[26] we assigned to **4c** the structure reported in Scheme 1. The spectroscopic data of **4c** are insufficient for its structure determination.

The other unexpected candidate to oxidize **6** to **3** could be the acid present. Since it has been recently reported that TFA can promote oxidative processes,[27] we examined this possibility. The N,N'-dihydroxy dimer **6a**, obtained from **3a** by reduction with hydrazo- benzene, when treated with TFA was suddenly retransformed into the dimer **3a**.

The presence of quinoneimine N-oxide **2a-c** is difficult to explain. At first this product was thought to derive from the disproportionation of two molecules of nitroxide (Scheme 4) as occurs in the case of indolinonic nitroxides. In order to verify this possibility, amines **8a-c** were syntethized to obtain authentic samples for assaying their presence in the reaction mixture. The amines **8a-c** were never found. The total absence of the amine from the reaction mixture and the fact that the yield of the quinoneimine **2a** increases by 100%, when carrying out the reaction of nitroxide **1a** in the presence of air, suggest that it is formed by an interaction of the nitroxide radical cation and oxygen of air. This kind of interaction was observed by us[28] and others[29] and proceeds as reported in the literature.



1 **2** **8a-c**

a: R= -H; R$_1$= -Ph; b: R= -OH*; R$_1$= -Ph; c: R= -C(CH$_3$)$_2$OH; R$_1$= -CH$_3$.

*: Spectroscopic data show that this enol ether assumes the ketonic form

Scheme 4

Generally, vinyl ethers in the presence of acid, undergo cleavage of the ethereal group.[30] According to the literature reports the dimer **3b** recovered in the reaction with acid, and the amine **8b**, bear a ketonic group at C-4; we have no explanation at the moment for the fact that quinoneimine N-oxide **2b** and quinoline **4b** keep the ethereal function.

EXPERIMENTAL

Melting points were measured on an Electrochemical Melting Point Apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer model 298 spectrophotometer. ^{1}H-NMR spectra were recorded in CDCl$_3$ on a Varian Gemini 200 at 200 MHz. Mass spectra were recorded on a Carlo Erba QMD 1000 spectrometer. EPR spectra were recorded on a Varian E4 spectrometer.

Nitroxides **1a,b** were prepared as reported in the literature.[12]

Synthesis of nitroxide 1c. A Grignard reagent solution of CH$_3$MgI (60 mmoles in 50 ml of Et$_2$O) was added to a 2-phenyl-4-carbethoxyquinoline-N-oxide[31] solution (10 mmoles in 80 ml of THF) under stirring in N_2 atmosphere and at room temperature. After 2h, the mixture was treated with a 0.5 M solution of NH_4Cl and extracted with $CHCl_3$. The organic layer was dried on Na_2SO_4 and oxidized with PbO_2 under magnetic stirring for 2h. The solution was filtered, evaporated to dryness and the residue was chromatographed on SiO_2 column, eluting with benzene. The red nitroxide radical was isolated as a pure, red powder after concentration. Yield 60%. M.p.= 148°C; ν_{max} (Nujol) 3480 (OH), 1600 cm^{-1}; m/z 294 (M^+), 236 (100%); hfcc's in $CHCl_3$: a_N=10.48, $a_H(3)$=1.07, $a_H(5,7)$=1.25, $a_H(4,6)$=3.35 Gauss; Analysis: Calcd. for $C_{19}H_{20}NO_2$: H, 6.85; C, 77.52; N, 4.76; Found: H, 6.72; C, 77.50; N, 4.80.

*Preparation of Quinoneimine N-oxides **2a-c**.* 0.5 mmoles of nitroxides **1a-c** were dissolved in 10 ml CH_3CN. An aqueous solution of cerium ammonium nitrate (Ce^{IV}) (0.5 mmoles in 1 ml of water) was added dropwise to the nitroxide solution. An additional mmole of solid Ce^{IV} salt was then added in small amounts to the reaction until complete disappearance of the nitroxide, by following the reaction through T.L.C.. The reaction was then poured into 20 ml water, extracted with 40 ml $CHCl_3$, washed twice with 20 ml water, dried over Na_2SO_4 and concentrated. The residue was chromatographed on preparative silica gel plates eluting with cyclohexane/ethyl acetate 8:2 for **2a-b**, and cyclohexane/ethyl acetate 6:4 for **2c**. From the yellow spots products **2a-c** were obtained, crystallized from petroleum ether 80°-100°. Yields as follows: **2a** (90%), **2b** (65%), **2c** (60%).

*Preparation of Amines **8a-c**.* 1 mmole of nitroxides **1a-c**, 5 ml glacial acetic acid and 500 mg of iron were refluxed altogether for 5 min. The iron was filtered off and the organic layer evaporated to dryness. The residue was taken up with 30 ml $CHCl_3$ and neutralized with 20 ml 10% Na_2CO_3. The organic layer was then washed twice with 20 ml water, dried over Na_2SO_4 and concentrated to a small volume. The residue was chromatographed on preparative silica gel plates eluting with cyclohexane/ethyl acetate 1:9 for **8a-b** and cyclohexane/ethyl acetate 7:3 for **8c**. The large fluorescent spot yielded 70% for **8a**, 68% for **8b**, and 64% for **8c** (crystallized from hexane).

*Reaction of **1a-c** with Trichloroacetic Acid.* Solutions of nitroxides **1a-c** (1 mmole in 10 ml of benzene) and of Trichloroacetic acid (TCA) (3 mmoles in 10 ml of benzene) were degassed separately under argon at room temperature, in a two-legged test-tube for 10 mins. The two solutions were then mixed together and degassed for a further 10 mins. The dark red colour of the nitroxide solution turned dark violet immediately on addition of the acid. The reaction was then neutralized with 10% Na_2CO_3 (50 ml), extracted with benzene (2 x 20 ml). The organic layer was washed with water (2 x 20 ml), dried over Na_2SO_4, evaporated to a small volume and then chromatographed on preparative silica gel plates eluting with cyclohexane/ethyl acetate 8:2 for nitroxides **1a-b**, and cyclohexane/ethyl acetate 6:4 for nitroxide **1c**. From the red spots, nitroxides **1a-c** were recovered. Yields as follows: **1a** (180 mg, 60%), **1b** (193 mg, 56%), **1c** (no nitroxide was recovered because of its instability). From the dark violet spots extracted with ethyl acetate and evaporated to dryness, fine bright fluorescent violet crystals of dimers **3a-c** were extracted. Yields as follows: **3a** (35 mg, 12%), **3b** (50 mg, 16%), **3c** (60 mg, 20%). The fluorescent spot was identified as 4-substituted 2,3-quinoline (**4a-c**). Yields as follows: **4a** (26 mg, 8%), **4b** (34 mg, 10%), **4c** (25 mg, 7%). The yellow spot was identified as quinoneimine N-oxides **2a-c** by comparison with authentic samples. Yields are as follows: **2a** (10 mg, 3%), **2b** (11 mg, 3%), **2c** (15 mg, 5%). Other minor unidentified spots were extracted from the reactions.

*Reaction of **1a-c** with Trifluoroacetic Acid.* Solutions of nitroxides **1a-c** (1 mmole in 10 ml of benzene) and of Trifluoroacetic acid (TFA) (3 mmoles in 10 ml of benzene) were reacted, worked up and chromatographed in the same way as for the reactions with TCA. From the red spots, nitroxides **1a-c** were recovered. Yields as follows: **1a** (135 mg, 45%), **1b** (113 mg, 33%), **1c** (60 mg, 20%). From the dark violet spots, dimers 3a-c resulted. Yields are as follows: **3a** (48 mg, 16%), **3b** (66 mg, 21%), **3c** (78 mg, 27%). From the fluorescent spots quinolines **4a-c** were recovered. Yields as follows: **4a** (15 mg, 5%), **4b** (23 mg, 7%), **4c** (16 mg,

Table 3. Analytical and Spectroscopic Data of Compounds 2a-c, 3a-c, 4a-c and 8a-c.

Comp.	NMR (δ, ppm) in $CDCl_3$	IR (ν, cm^{-1})	Mass Spectra	Melting Point	Calc. % Found (%)		
2a	**6.23** (1H, d, J=1.9 Hz, H-C5); **6.60** and **6.67** (2H, AB, J=10.1 Hz, H-C3 and H-C4); **6.64** (1H, dd, J=1.9 and 10.2 Hz, H-C7); **7.34** (10H, m, arom.); **7.95** (1H, d, J=10.2 Hz, H-C8)	1625, 1580, 1550	313 (M^+), 313 (100%)	192°C	H 4.82 (4.77)	C 80.49 (80.36)	N 4.47 (4.50)
2b	**1.43** (3H, t, J=7.0 Hz, $OCH_2\underline{CH_3}$); **3.97** (2H, q, J=7.0 Hz, $O\underline{CH_2}CH_3$); **5.59** (1H, s, H-C3); **6.63** (1H, dd, J=2.1 and 10.2 Hz, H-C7); **6.70** (1H, d, J=1.8 Hz, H-C5); **7.33** (10H, m, arom.); **7.92** (1H, d, J=10.2 Hz, H-C8)	1660, 1625, 1595, 1555	357 (M^+), 357 (100%)	183°C	H 5.36 (5.21)	C 77.29 (77.17)	N 3.92 (4.03)
2c	**1.67** (6H, s, HO-C($\underline{CH_3}$)$_2$); **2.05** (3H, s, CH_3); **6.42** (1H, s, H-C3); **6.60** (1H, dd, J=2.0 and 10.2 Hz, H-C7); **7.18** (1H, d, J=2.0 Hz, H-C5); **7.36** (5H, m, arom.); **7.97** (1H, d, J=10.2 Hz, H-C8)	3330, 1615, 1580, 1545	309 (M^+), 309 (100%)	147°C	H 6.19 (6.05)	C 73.77 (73.64)	N 4.53 (4.70)
3a	not resolved	1600	594 (M^+), 501 (100%)	225°C	H 5.08 (4.99)	C 84.82 (84.72)	N 4.71 (4.88)
3b	**3.40** (2H, s, H_2-C3); **6.71** (2H, m, arom.); **7.29** (11H, m, arom.); **7.74** (1H, bdd, J=7.6 and 1.3 Hz, arom.)	1730, 1610	626 (M^+), 497 (100%)	182°C	H 4.82 (4.72)	C 80.49 (80.31)	N 4.47 (4.55)
3c	**1.67** (6H, s, HO-C($\underline{CH_3}$)$_2$); **2.05** (3H, s, CH_3); **6.43** (1H, s, H-C3); **6.61** (1H, dd, J=1.9 and 10.2 Hz, H-C7); **7.045** (1H, d, J=1.8 Hz, H-C5); **7.34** (5H, m, arom.); **7.98** (1H, d, J=10.2 Hz, H-C8)	3377, 1733, 1615, 1591	586 (M^+) 524 (100%)	151°C	H 6.53 (6.35)	C 77.79 (77.60)	N 4.77 (4.85)
4a	**7.26** (9H, m, arom.); **7.46** (2H, m, arom.); **7.61** (1H, t, J=6.1 Hz, H-C6); **7.78** (1H, t, J=6.1 Hz, H-C7); **7.9** (1H, d, J=6.1 Hz, H-C5); **8.24** (1H, s, H-C4)	1615, 1590, 1020, 695	281 (M^+), 280 (100%)	77°C	H 5.37 (5.28)	C 89.65 (89.52)	N 4.98 (5.10)
4b	**1.16** (3H, t, $OCH_2\underline{CH_3}$); **3.69** (2H, q, $O\underline{CH_2}CH_3$); **7.28** (11H, m, arom.); **7.60** (1H, bt, J=7.6 Hz, H-C6); **7.78** (1H, bt, J=7.3 Hz, H-C7); **8.23** (1H, bd, J=8.2 Hz, H-C5)	1580, 1570, 1105, 1055, 695	325 (M^+), 296 (100%)	122°C	H 5.89 (5.70)	C 84.89 (84.65)	N 4.30 (4.35)
4c	**1.64** (6H, s, HO-C($\underline{CH_3}$)$_2$); **2.30** (3H, s, CH_3); **7.23** (3H, m, arom.); **7.46** (3H, m, arom.); **7.66** (1H, bt, J=7.6 Hz, H-C7); **8.06** (1H, bd, J=7.6 Hz, H-C5); **8.70** (1H, bd, J=7.9 Hz, H-C8)	3260, 1555, 1135, 760, 705	277 (M^+), 218 (100%)	150°C	H 6.90 (6.76)	C 82.28 (82.22)	N 5.05 (5.13)
8a	**1.65** (1H, bs, NH); **5.91** (1H, d, J=9.9 Hz, H-C3); **6.51** (1H, d, J=9.9 Hz, H-C4); **6.52** (1H, t, J=8.4 Hz, H-C7); **6.62** (1H, d, J=7.3, arom.); **6.62** (1H, d, J=7.4, arom.); **7.01** (1H, t, J=7.7 Hz, H-C5); **7.3** (10H, m, arom.)	3400, 1605	283 (M^+), 206 (100%)	77°C	H 6.05 (6.00)	C 89.01 (88.89)	N 4.94 (5.03)
8b	**3.38** (2H, s, H_2-C3); **5.16** (1H, bs, NH); **6.69** (1H, ddd, J=8.0, 7.0 and 1.0 Hz, arom.); **6.75** (1H, dd, J=7.0 and 1.0 Hz, arom.); **7.3** (11H, m, arom.); **7.73** (1H, dd, J=8.0 and 1.0 Hz, arom.)	3240, 1645, 1610, 1580	299 (M^+), 222 (100%)	205°C	H 5.72 (5.60)	C 84.25 (84.17)	N 4.68 (4.77)
8c	**1.60** (6H, s, HO-C($\underline{CH_3}$)$_2$); **1.69** (3H, s, CH_3), **5.81** (1H, s, H-C3); **6.58** (1H, dd, J=7.6 and 1.5 Hz, H-C4); **6.67** (1H, dt, J=7.6 and 1.5 Hz, H-C5); **7.02** (1H, dt, J=7.9 and 1.5 Hz, H-C6), **7.29** (3H, m, arom.); **7.49** (2H, m, arom.); **7.81** (1H, dd, J=7.9 and 1.5 Hz, H-C7)	3560, 3370, 1710, 1600	279 (M^+), 264 (100%)	54°C	H 7.58 (7.42)	C 81.68 (81.50)	N 5.01 (5.20)

6%). From the yellow spots, products **2a-c** were obtained. Yields as follows: **2a** (9 mg, 3%), **2b** (7 mg, 4%), **2c** (3 mg, 1%). The reaction was repeated also with an excess of TFA (3 ml in 10 ml of benzene). Yields are as follows: **3a** (148 mg, 50%), **3b** (110 mg, 36%), **3c** (133 mg, 45%), **4a** (96 mg, 34%), **4b** (65 mg, 20%), **4c** (68 mg, 25%), **2a** (10 mg, 3%), **2b** (18 mg, 6%), **2c** (9 mg, 3%), Other minor unidentified spots were extracted from the reactions.

Crystal structure of 6,6'-bis-(1-oxide-1,2,6,8a-tetrahydroquinoline)ylidene (3a)

Crystals are dark violet prisms. Lattice constants were determined repeatedly rectifying on the diffractometer the values of $(\vartheta,\chi,\varphi)_{hkl}$ angles by thirty reflections to have the maximum of the peak when the angles were moving by 0.001° as a maximum.

Crystal data - $C_{42}H_{30}N_2O_2$, $M = 594.7$; monoclinic, $a = 20.547(4)$, $b = 14.381(3)$, $c = 11.097(2)$ Å; $\beta = 110.5(1)^\circ$, $U = 3071.4(23)$ Å^3; $Z = 4$, $D_c = 1.29$ g cm^{-3}; Cu-$K\alpha$ radiation, $\lambda = 1.5418$ Å, $\mu = 5.8$ cm^{-1}. Space group $C\,2/c$ (C_{2h}^6, No. 15) from structure determination.

Intensity data were collected at 295 *K* on a Siemens AED single-crystal diffractometer in the range $3\backslash\vartheta\backslash70^\circ$ using Ni-filtered Cu-$K\alpha$ radiation. The angles for every reflection were determined on the basis of the orientation matrix and the outline of the diffraction peak was collected in the ϑ-2ϑ step scanning mode using a scan width from $(\vartheta-0.60)^\circ$ to $(\vartheta+0.60+\Delta\lambda/\lambda\ \mathrm{tg}\vartheta)^\circ$. The intensities I_{hkl} were determined by analyzing the reflection profiles.[32] 2917 Independent reflections were measured, 1072 of which were used in the crystal analysis having $I_{hkl} > 2\sigma(I_{hkl})$, $\sigma(I_{hkl})$ being based on statistic counting. One standard reflection, measured every 50 collected reflections to monitor crystal decomposition and instrumental linearity, showed no significant variation. Intensities I_{hkl} were corrected for Lorentz and polarization effects. The dimensions of the crystal were 0.05, 0.09, 0.24 mm. No absorption corrections were applied.

Structure analysis and refinement - The structure was solved by direct methods by use of the SHELXS86 program[32] and refined by SHELX76[33] with cycles of full-matrix anisotropic least-squares (hydrogen atoms isotropically) up to $R = 0.034$, $R_w = 0.036$; $\Sigma w(F_o-F_c)^2$ minimized with $w = 0.1898/[\sigma^2(F_o)+0.0033F_o^2]$. Atomic scattering factors from International Tables for X-ray Crystallography.[34]

Crystal structure of 2,3-diphenylquinoline (4a)

Crystals are pale pink prisms. Cell parameters were derived as before.

Crystal data. $C_{21}H_{15}N$, $M = 281.4$. Monoclinic, $a = 8.734(2)$, $b = 16.674(3)$, $c = 11.112(3)$ Å; $\beta = 104.1(1)^\circ$, $U = 1569.5(9)$ Å^3; $Z = 4$, $D_c = 1.19$ g cm^{-3}; Cu-$K\alpha$ radiation, $\lambda = 1.5418$ Å, $\mu = 5.0$ cm^{-1}. Space group $P\,2_1/n$ (C_{2h}^6, No. 15) from systematic absences.

Intensity data are collected as before. Of 3249 measured reflections ($-10\leq h\leq10$, $0\leq k\leq20$, $0\leq l\leq13$), 1759 symmetry independent were used in the crystal analysis. The dimensions of the crystal were 0.43, 0.10, 0.29 mm. No absorbtion corrections were applied.

Structure analysis and refinement. The structure was solved as before and refined by cycles of full-matrix anisotropic least-squares (hydrogen atoms isotropically) up to $R = 0.039$, $R_w = 0.044$. The weighting function was of the form $1/w = \sigma^2(F_o)+0.0033F_o^2$.

All the hydrogen atoms were located in the difference-Fourier map. Atomic scattering factors from International Tables for X-ray Crystallography.[35]

All the calculations were carried out on the GOULD 6040 POWERNODE computer of the Centro di Studio per la Strutturistica Diffrattometrica del C.N.R. di Parma and the Cambridge Crystallographic Data Files were used for bibliographic searches through the Servizio Italiano di Diffusione Dati Cristallografici di Parma.

REFERENCES

1. Swartz, H. M. in *Adv. Magn. Reson. Imaging:* Flig, E. Ed.; Ablex Publishing: Norwood, N.J., 1989.
2. Chignell, C. F. in *Spin Labelling II, Theory and Application:* Berliner, L. J. Ed.; Acad. Press: N. Y. London, 1979; p. 223.

3. Mitchell, J. B.; Samuni, A.; Krishna, N. C.; DeGraff, W. G.; Ahn, N. S.; Samuni, U.; Russo, A. *Biochem.* **1990**, 2802.
4. McConnell, H. N. in *Spin Labelling, Theory and Application:* Berliner, L. J. Ed.; Acad. Press: N. Y. London, 1976; p. 525.
5. Morrisett, J. D. *ibid.*, p. 274.
6. Swartz, H. M.; Pals, M. A. in *Handbook of Biomedicine of Free Radicals and Antioxidants:* Miguel, J.; Weber, H.; Quintanilha A. Eds.; CRC Press: Boca Raton, FL, 1989; Vol. 3, p.141.
7. Jansen, E. G.; Hair, D. L.; Coulter, G. A.; Stronks, H. J.; Krygsman, P. H.; Towner, R. A.; Hilborn, J. W. *J. Org. Chem.* **1989**, *54*, 2915.
8. Ueno, I.; Kohno, M.; Mitsuta, K.; Mizuta, Y.; Kanegasaki, S. *J. Biochem.* **1989**, *105*, 905; Mottley, C.; Mason, R. P. in *Biological Magnetic Resonance:* Berliner, L. J.; Reuben, J. Eds.; Plenum Press: N. Y. London, 1989; Vol. 8. p. 489.
9. Miller, W. G. in *Spin Labelling II, Theory and Application*: Berliner, L. J. Ed.; Acad. Press: N. Y. London, 1979; p. 173; Rånby, B.; Rabek, J. F. *ESR Spectroscopy in Polymer Research:* Springer Verlag: Berlin N. Y., 1977.
10. Rosantzev, E. G. *Free Nitroxyl Radicals*, Ulrich, H. Ed.; Plenum Press: N. Y. London, 1970.
11. Volodorsky, L. B. *Imidazoline Nitroxide:* Miguel, J.; Weber, H.; Quintanilha A. Eds.; CRC Press: Boca Raton, FL, 1988; Vol. I and III.
12. Berti, C.; Colonna, M.; Greci, L.; Marchetti, L. *Tetrahedron* **1976**, *32*, 2147.
13. Antosiewicz, J.; Bertoli, E.; Damiani, E.; Greci, L.; Popinigis, J.; Przybylski, S.; Tanfani, F.; Wozniak, M. *Free Radical Biology and Medicine*, accepted for publication, 1993.
14. Carloni, P.; Greci, L.; Stipa, P.; Rizzoli, C.; Sgarabotto, P.; Ugozzoli, F. *Polymer Deg. and Stab.* **1993**, *39*, 73; Alberti, A.; Carloni, P.; Greci, L.; Stipa, P.; Neri, C. *ibid.*, **1993**, *39*, 215.
15. Cardellini, L.; Carloni, P.; Greci, L.; Stipa, P.; Faucitano, A. *Gazz. Chim. Ital.* **1989**, *119*, 621, and references reported therein.
16. Carloni, P.; Greci, L.; Stipa, P.; Eberson, L. *J. Org. Chem.* **1991**, *56*, 4733.
17. Lenner, M. and Lindgren, O. *Acta Cryst.* **1976**, *B32*, 1903; Folting, K. and L. Merrit, L. Jr. *Acta Cryst.* **1977**, *B33*, 3540; Gdaniec, M.; Jaskolski, M.; Kosturkiewicz, Z. *Acta Cryst.* **1977**, *B33*, 3558; Levina, O. I.; Rau, V. G.; Potekhin, K. A.; Kurkutova, E. N.; Pakhomov, I. G.; Struchkov, Yu. T. *Cryst. Struct. Comm.* **1982**, *11*, 1899; Das, K.; Sinha, U. C.; Talwar, S. S.; Kamath, M. B.; Bohra, R. *Acta Cryst.* **1990**, *C46*, 2126.
18. Benassi, R.; Taddei, F.; Greci, L.; Marchetti, L.; Andreetti, G. D.; Bocelli, G.; Sgarabotto, P. *J. Chem. Soc. Perkin Trans. 2* **1980**, 786.
19. Pauling, L. *The Nature of the Chemical Bond:* Cornell University Press, 1960.
20. Rizzoli, C.;Sgarabotto, P.; Ugozzoli, F.; Carloni, P.; Damiani, E.; Greci, L.; Stipa, P. *J. Het. Chem.*, in press.
21. Rosantzev, E. G.; Sholle, V. D. *Synthesis* **1971**, 401.
22. Forrester, A. R.; Hay, J. M.; Thomson, R. H. *Organic Chemistry of Stable Free Radicals:* Academic Press: London, 1968; p. 225.
23. Greci, L. *Tetrahedron* **1983**, *39*, 667.
24. Aurich, H. G. *Nitroxides* in *Amino, Nitroso and Nitro Compounds and their Derivatives, Part. 1:* Patai, S.; Wiley, J. and Sons, Eds.; N. Y., 1982; p. 598.
25. Aurich, H. G. *Pure and Appl. Chem. (2)* **1990**, *62*, 183.
26. March, J.; *Advanced Organic Chemistry:* Wiley, J. and Sons, Eds.; N. Y., 1985; p. 950.
27. Eberson, L.; Radner, F. *J. Chem. Soc. Chem. Comm.* **1991**, 1233.
28. Carloni, P.; Eberson, L.; Greci, L.; Stipa, P.; Tosi, G. *J. Chem. Soc. Perkin Trans. 2* **1991**, 1779.
29. Effemberger, F.; Stohrer, W.; Mack, K.; Reisinger, F.; Seufert, W.; Kramer, H. E. A.; Föll, R.; Vogelmann, E. *J. Am. Chem. Soc.* **1990**, *112*, 4849.
30. March, J.; *Advanced Organic Chemistry:* Wiley, J. and Sons, Eds.; N. Y., 1985; p. 331.
31. Monti, L.; Franchi, G. *Gazz. Chim. Ital.* **1951**, *81*, 544.
32. Lehmann, M. S.; Larsen, F. K. *Acta Cryst.* **1974**, *A30*, 580.
33. Sheldrick, G. M. *SHELXS86 - Program for the Solution of Crystal Structures:* University of Göttingen, Germany, 1986.
34. Sheldrick, G. M. *SHELX76 - System of Computer programs for Crystal Structure Determination:* University of Cambridge, 1976.
35. *International Tables for X-ray Crystallography:* Kynoch Press: Birmingham, England, 1974; Vol. IV.