

## Nitroxide Radicals of some *N*-Phenyl Substituted 1,4- and 1,2-Phenylenediamines

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**Summary.** Several *N*-phenyl substituted 1,4- and 1,2-phenylenediamines were oxidized using  $\text{RO}_2^\cdot$  radicals and 3-chloroperbenzoic acid. EPR spectroscopy confirmed the generation of nitroxide radicals originating from the oxidation of the bridging -NH-group. No radical products suggesting the simultaneous reaction with the  $\text{NH}_2$ -group were observed. Only in the case of 1,4-phenylenediamine, a low concentration of nitroxide radical  $\text{H}-\text{NO}^\cdot-\text{C}_6\text{H}_4-\text{NH}_2$  was obtained. In *o*-aminodiphenylnitroxide the steric effect of the  $\text{NH}_2$ -group causes a partially asymmetrical spin density distribution in both phenyl rings.

**Keywords.** 1,4-Phenylenediamine; 1,2-Phenylenediamine; Nitroxide radicals; EPR.

### Introduction

One electron chemical or electrochemical oxidation of 1,4-phenylenediamine and its *N*-phenyl derivative leading to the formation of the corresponding primary cation radicals has been frequently reported in the last decades [1–4]. The analogous oxidation of 1,2-phenylenediamine and its *N*-phenyl derivative affords only the secondary radical products, which have been attributed to the dihydrophenazinium cation radicals [4]. On the other side, the tendency towards the formation of nitroxide radicals by oxidation with  $\text{RO}_2^\cdot$  radicals and peroxy acids is a characteristic feature of many primary and secondary amines. The stable nitroxide radicals  $\text{R}^1-\text{NO}^\cdot-\text{R}^2$  are formed from secondary amines  $\text{R}^1-\text{NH}-\text{R}^2$ , when the -NH- bridge is situated between two aromatic substituents. Especially, the substituted diphenylnitroxides ( $\text{R}^1 = \text{R}^2 = \text{substituted phenyl}$ ) have been studied intensively since the early sixties, as evidenced by the numerous EPR data in catalogues [5].

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A high stability characterizes also those nitroxides having a phenyl ring together with different *N*-heterocyclic rings ( $R^1$  = pyrazole, triazole, tetrazole, or benzimidazole ring,  $R^2$  = substituted phenyl) [6, 7]. The nitroxide radicals  $R^1\text{--NO}\cdot\text{H}$  are generated by oxidation of the  $\text{NH}_2$ -group of substituted anilines ( $R^1$  = substituted phenyl ring) by means of peroxy acids [8, 9]. In some cases, the generation of peroxyaryl nitroxides  $\text{RO}_2\text{--NO}\cdot\text{R}^1$  has been suggested by  $\text{RO}_2\cdot$  oxidation of the  $\text{NH}_2$ -substituent bound to the *N*-heterocyclic ring ( $R$  = *t*-butyl,  $R^1$  = *N*-heterocyclic ring) [10]. Up to now, there is only a limited number of EPR data available on the  $\text{RO}_2\cdot$  oxidation of aromatic molecules simultaneously containing two amino groups (bridging -NH-group and  $\text{NH}_2$ -substituent) in different combinations [10]. In this paper we attempted to obtain some new information on this topic.

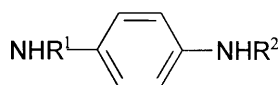
## Results and Discussion

In the framework of the investigated compounds -NH- and  $\text{NH}_2$ -groups occur in different combinations (two  $\text{NH}_2$ -groups – **1a**, **2a**; -NH- and  $\text{NH}_2$ -group – **1b**, **2b**; two -NH-groups – **1c**, **1d**) and they can be oxidized independently. Therefore, the identification and interpretation of radical products can determine the active site of the primary attack of the oxidation agent. The stability and the time dependence of the EPR signal can reflect the course of the oxidation in the consecutive steps.

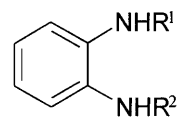
Two different methods were applied for the oxidation of compounds **1** and **2**. To evaluate the reactivity of both substrates towards the radical oxidation,  $t\text{-BuO}_2\cdot$  radicals were prepared by decomposition of  $t\text{-BuOOH}$  with  $\text{PbO}_2$  [11, 12] in benzene solution and used as the oxidative agent (Method A). Under these experimental conditions the formation of nitroxide radicals proceeds according to the mechanism proposed by Thomas [13]. The nonradical oxidation was performed with 3-chloroperbenzoic acid in benzene solution (Method B). In this case hydroxylamines are supposed to be formed as intermediates [14]. In the consecutive step they undergo hydrogen abstraction under formation of the corresponding nitroxide radicals. The experimental results obtained by EPR measurements are summarized as follows.

### 1,4-Phenylenediamine (**1a**)

By the reaction of **1a** with  $\text{RO}_2\cdot$  radicals no radical products were observed. Performing the reaction with 3-chloroperbenzoic acid, the nitroxide radicals

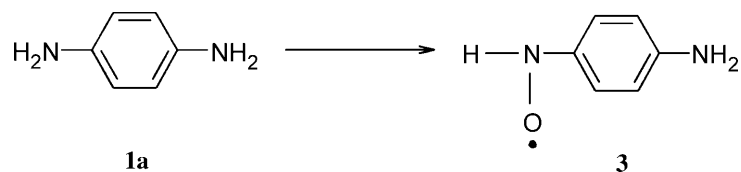


- 1a**  $R^1 = R^2 = \text{H}$   
**1b**  $R^1 = \text{H}, R^2 = \text{Ph}$   
**1c**  $R^1 = R^2 = \text{Ph}$   
**1d**  $R^1 = (\text{CH}_3)_2\text{CH}-(\text{CH}_2)_2-$ ,  $R^2 = \text{Ph}$



- 2a**  $R^1 = R^2 = \text{H}$   
**2b**  $R^1 = \text{H}, R^2 = \text{Ph}$

Formulae 1 and 2



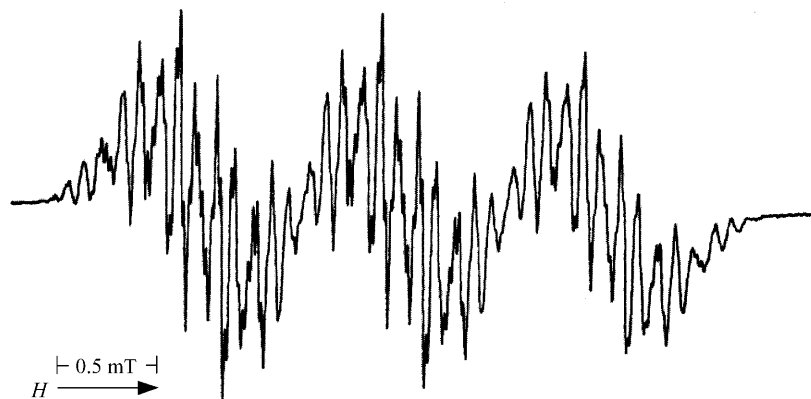
Scheme 1

( $g = 2.0050$ ) were generated in low concentration. The analysis of the EPR spectrum proved the splittings  $a_{\text{N}}(\text{NO}) = 0.920$  mT,  $a_{\text{H}}(1\text{H}) = 1.006$  mT,  $a_{\text{H}}(2\text{H}) = 0.290$  mT,  $a_{\text{H}}(2\text{H}) = 0.095$  mT,  $a_{\text{N}}(1\text{N}) = 0.050$  mT, which can be ascribed to the nitroxide radical **3** (Scheme 1).

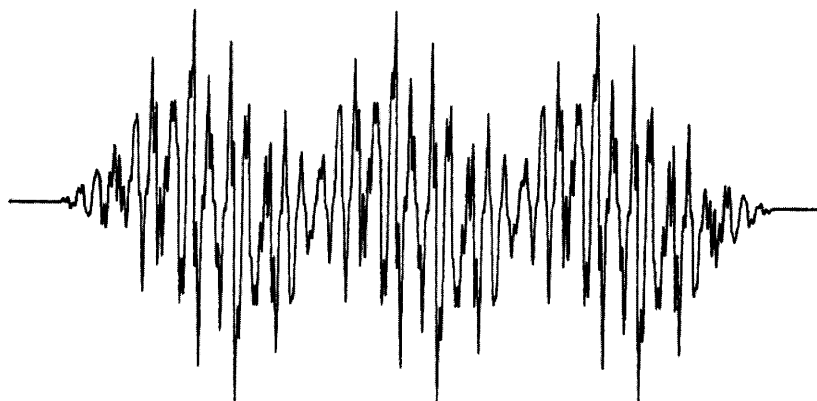
#### 4-Aminodiphenylamine (**1b**)

The EPR spectrum outlined in Fig. 1 was obtained applying either  $\text{RO}_2^\cdot$  radicals or 3-chloroperbenzoic acid as oxidation agent. The EPR parameters extracted from the

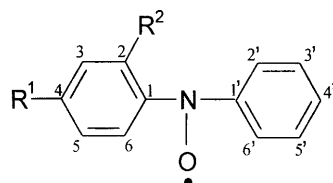
#### EXPERIMENT



#### SIMULATION



**Fig. 1.** Experimental and simulated EPR spectrum of the nitroxide radical **4** in benzene solution



- |                                                                                         |                                                   |
|-----------------------------------------------------------------------------------------|---------------------------------------------------|
| <b>4</b> $R^1 = \text{NH}_2$ $R^2 = \text{H}$                                           | <b>8</b> $R^1 = \text{H}$ , $R^2 = \text{CH}_3$   |
| <b>5</b> $R^1 = \text{C}_6\text{H}_5\text{-NH-}$ , $R^2 = \text{H}$                     | <b>9</b> $R^1 = \text{H}$ , $R^2 = \text{COOH}$   |
| <b>6</b> $R^1 = (\text{CH}_3)_2\text{CH-}(\text{CH}_2)_2\text{-NH-}$ , $R^2 = \text{H}$ | <b>10</b> $R^1 = \text{H}$ , $R^2 = \text{NO}_2$  |
| <b>7</b> $R^1 = \text{H}$ , $R^2 = \text{NH}_2$                                         | <b>11</b> $R^1 = \text{H}$ , $R^2 = \text{OCH}_3$ |

**Formula 3****Table 1.** EPR parameters of nitroxide radicals **4–11** in benzene ( $g \cong 2.0050$ )

Radical	$a_{\text{N}}(\text{NO})$	$a_{\text{H}}(6)$	$a_{\text{H}}(3,5)$	$a_{\text{X}}(\text{R}^1)$	$a_{\text{X}}(\text{R}^2)$	$a_{\text{H}}(2',6')$	$a_{\text{H}}(3',5')$	$a_{\text{H}}(4')$
<b>4</b>	0.991	0.201	0.085	0.072(1N) 0.021(2H)	0.201	0.179	0.071	0.195
<b>5</b>	0.960	0.182	0.074	0.038 <sup>a</sup>	0.182	0.182	0.074	0.182
<b>6</b>	0.961	0.174	0.085		0.177	0.177	0.085	0.177
<b>7</b>	1.010 <sup>b</sup>							
<b>8<sup>c</sup></b>	0.981					0.270	0.100	0.270
<b>9<sup>d</sup></b>	1.070					0.270	0.084	0.270
<b>10</b>	0.892	0.080 <sup>e</sup>	0.070 <sup>e</sup>	0.090 <sup>e</sup>	0.025(1N)	0.230	0.090 <sup>e</sup>	0.230
<b>11</b>	0.995	0.080	0.060	0.080		0.250	0.090	0.250

<sup>a</sup> Splitting from nitrogen atom of NH group<sup>b</sup> Splitting constant in cyclohexane; due to the complexity of the EPR spectrum (Fig. 2) other splittings were not determined<sup>c</sup> EPR data taken from Ref. [15]<sup>d</sup> EPR data taken from Ref. [5]<sup>e</sup> Hydrogen splittings in positions 3,4,5,6,3',5' can mutually be exchanged

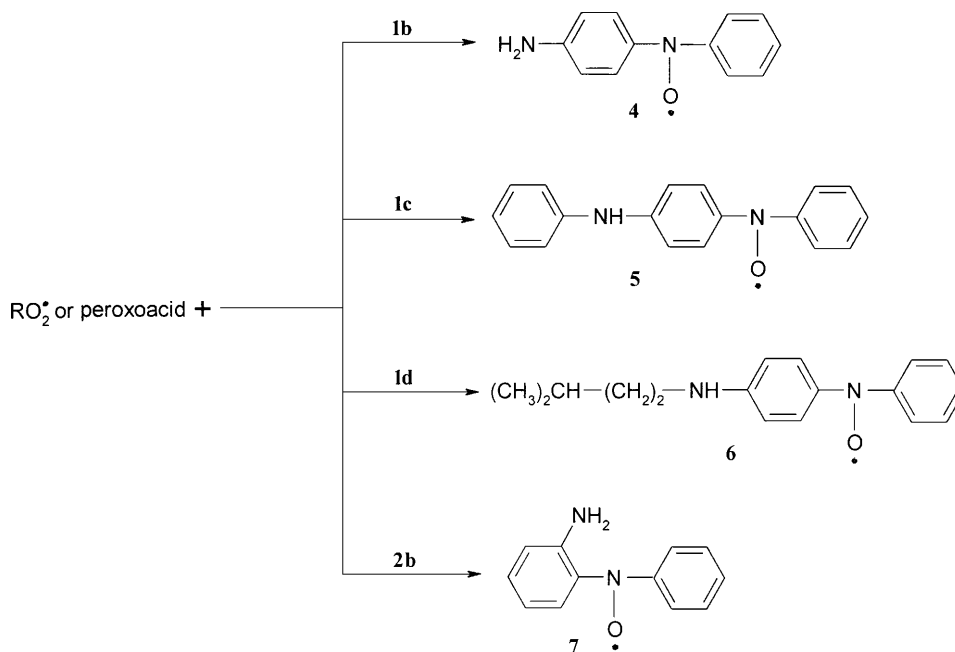
simulation confirmed the generation of the nitroxide radical **4** (Table 1, Scheme 2), *i.e.* the oxidation preferentially proceeds on the secondary amino group.

#### *N,N'*-Diphenyl-1,4-phenylenediamine (**1c**)

Independent on the oxidation method, one type of EPR spectrum was registered. As follows from the splitting constants (Table 1), the nitroxide **5** (Scheme 2) is unambiguously formed, as the result of oxidation of one bridging -NH-group.

#### *N*-(3-Methylbutyl)-*N'*-phenylbenzene-1,4-diamine (**1d**)

One type of nitroxide radical was detected applying both oxidation methods. The inspection of the EPR spectrum showed that this radical is produced by oxidation of the -NH-group situated between the two phenyl rings (radical **6** in Scheme 2).



Scheme 2

### 1,2-Phenylenediamine (**2a**)

No radicals were observed by oxidation with  $\text{RO}_2^\bullet$  radicals as well as using 3-chloroperbenzoic acid. After addition of the oxidation system a black insoluble compound was precipitated.

### 2-Aminodiphenylamine (**2b**)

The unresolved EPR spectrum enabling only the determination of the basic  $a_{\text{N}}(\text{NO})$  splitting was obtained by the oxidation of **2b** with  $\text{RO}_2^\bullet$  radicals and 3-chloroperbenzoic acid in benzene solution. The high-resolution EPR spectrum outlined in Fig. 2 was obtained when the oxidation was carried out in cyclohexane.

With respect to the above mentioned experimental data, the oxidation of amines **1** and **2** by  $\text{RO}_2^\bullet$  radicals and 3-chloroperbenzoic acid represents an effective method for the preparation of nitroxide radicals. The only exception is the behaviour of 1,2-phenylenediamine (**2a**), where no radical products were observed in the course of the oxidation. The generation of the nitroxide radical **3** from 1,4-phenylenediamine (**1a**) shows that this compound behaves like a derivative of aniline, where the formation of a nitroxide radical  $\text{Ph}-\text{NO}-\text{H}$  was proved [8]. On the other hand, *N*-phenyl substituted 1,4-phenylenediamine **1b** was evidently oxidized on the secondary -NH-group and the nitroxide radical **4** was produced. This conclusion is supported by comparison of the simulated and measured EPR spectra (Fig. 1), where besides the basic nitrogen splitting also the splittings from protons of two phenyl rings and atoms from the  $\text{NH}_2$ -group were found (Table 1). All splitting constants are comparable with those characterizing the nitroxides from

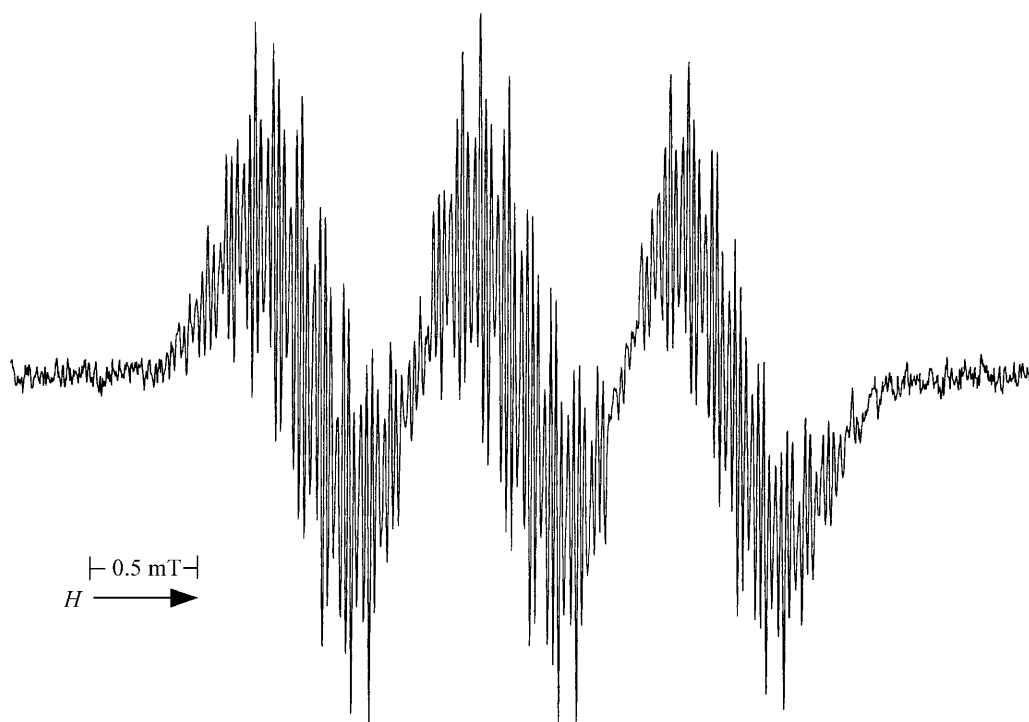


Fig. 2. Experimental EPR spectrum of the nitroxide radical **7** in cyclohexane solution

*para* substituted diphenylamines [5]. The stability of EPR signal documents that the  $\text{NH}_2$ -group in *para* position of the nitroxide radical **4** is not attacked in the consecutive steps of the reaction. However, this fact does not exclude the simultaneous attack on the primary  $\text{NH}_2$ -group in general. The EPR experiments only point out that the stable nitroxides result from the oxidation of the secondary -NH-group.

The idea of the simultaneous oxidation of both amino groups in **1b** (and also in **2b**) was supported by IR measurements. The IR spectra of the amino substituted diphenylamines **1b** and **2b** in the region  $3360\text{--}3420\text{ cm}^{-1}$  are composed of two bands, typical for the NH vibrations of  $\text{NH}_2$ - and -NH-groups. The intensities of both signals decrease with time, when **1b** and **2b** are oxidized by the system  $\text{PbO}_2/t$ -butylhydroperoxide.

As expected, the nitroxide radical **5** was easily formed from *N,N'*-diphenyl-1,4-phenylenediamine (**1c**) applying both oxidation methods. At ambient temperature, its EPR signal is stable for more than 1 hour. This fact proved that the second bridging -NH-group does not interact with the oxidative agents in the consecutive reaction. Similarly as with the nitroxide radical **4**, the splitting constants obtained by simulation (Table 1) agreed with typical values for diphenylamine nitroxides [5]. It should be also mentioned that replacing one phenyl group in compound **1c** by an alkyl group (**1d**) two different bridging -NH-groups are available for the reaction with an oxidizing agent. The analysis and simulation of the EPR spectrum of the generated nitroxide radical confirmed the preferential oxidation of the -NH-group situated between two phenyl rings (radical **6** in Scheme 2).

1,2-Phenylenediamine (**2a**) was evidently resistant towards the oxidation performed with both experimental methods. On the other side, the *N*-phenyl substituted 1,2-phenylenediamine **2b** could be easily oxidized to the corresponding nitroxide **7** (Fig. 2, Scheme 2) either with peroxy radicals or 3-chloroperbenzoic acid.

The stability of the EPR signal with time suggested that the  $\text{NH}_2$ -group does not exhibit follow-up reactions with the oxidants. From the spectroscopic point of view, the radical **7** can be considered as a steric hindered nitroxide. Therefore, the similarity with the properties of *ortho*-methyl substituted diphenylnitroxides investigated by Yamauchi *et al.* [15] was to be expected. Steric effects in 2-methyldiphenylnitroxide (**8**) were interpreted in terms of the repulsion between the *ortho*-substituents resulting in a distortion of the N–C bond between the nitrogen atom of the nitroxide fragment and the carbon atom of the *ortho*-methyl substituted phenyl ring. Under this condition, the spin density in the radical is largely distributed within the unsubstituted phenyl ring (Table 1, radical **8**). The quartet 1:3:3:1 splitting ( $a_{\text{H}} = 0.270 \text{ mT}$ ) from three nearly equivalent protons in *ortho* and *para* position of the phenyl ring (besides the basic nitrogen triplet splitting) dominates in the EPR spectrum, while the splittings from the protons of *ortho*-substituted phenyl ring are substantially lower. In a similar way, the EPR spectrum of 2-carboxydiphenylnitroxide (**9**) (Table 1) has been interpreted [5]. Although the complete simulation of the EPR spectrum of nitroxide **7** is still an open problem (too many lines, poor resolution at the edge of the EPR spectrum), no typical quartet splitting of the basic nitrogen triplet ( $a_{\text{N}}(\text{NO}) = 1.010 \text{ mT}$ ) is involved. This implies that the magnitude of the repulsion depends on the electron-donating and electron-accepting character of the *ortho* substituent. To obtain more detailed information about this influence on the spin distribution in mono substituted *ortho*-diphenylnitroxides, further radicals were prepared. By oxidation of 2-nitrodiphenylamine with 3-chloroperbenzoic acid 2-nitrodiphenylnitroxide (**10**) (Table 1) is produced. The inspection of its EPR spectrum reveals that, similarly as with 2-methyldiphenylnitroxide, the additional quartet 1:3:3:1 splitting ( $a_{\text{H}} = 0.230 \text{ mT}$ ) of three basic lines is involved. This quartet splitting dominates also in the EPR spectrum of 2-methoxydiphenylnitroxide (**11**) (Table 1) prepared by the spin-trapping method (see Experimental part). With respect to these data, it can be concluded that, when compared with other mono *ortho* substituted nitroxides, the impact of repulsion in 2-aminodiphenylnitroxide (**7**) is not very significant. The spin density distribution in both phenyl rings is evidently less “asymmetrical” and, as a result, a very complex EPR spectrum is observed.

## Experimental

### Materials

All chemicals were commercially available. They were used without further purification.

### Methods and Apparatus

The oxidation of **1** and **2** either with  $\text{RO}_2^{\cdot}$  radicals (Method A) or 3-chloroperbenzoic acid (Method B) was performed at ambient temperature according to the procedures described in Refs. [12, 16].

2-Methoxydiphenylnitroxide (**11**) was prepared by spin trapping of 2-methoxyphenyl radicals with nitrosobenzene in benzene solution. 2-Methoxyphenyl radicals were generated by the addition of  $\text{Pb}(\text{OAc})_4$  to a benzene solution of the corresponding 2-methoxy substituted 2,2-diacyl-1-arylhydrazine [17].

EPR spectra were recorded with a Bruker 200E-SRC spectrometer and a SpectraNova (E-I-A Warenhandels GmbH) spectrometer. Their simulation was carried out using the computer Aspect 2000 of the spectrometer. The IR spectra were measured in benzene solution with a Nicolet Impact 400 spectrometer.

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