# Aminoxyl Radicals Formed in the Reaction Between 2-Oximinopropanoic Acid or 2-Oximinopropane and Short-Lived Radicals Studied by EPR Spectroscopy

## Carl Lagercrantz

Department of Medical Physics, University of Göteborg, P.O. Box 33031, S-400 33 Göteborg, Sweden

Lagercrantz, C., 1991. Aminoxyl Radicals Formed in the Reaction Between 2-Oximinopropanoic Acid or 2-Oximinopropane and Short-Lived Radicals Studied by EPR Spectroscopy. – Acta Chem. Scand. 45: 949–952.

 $R^1R^2C(R)\dot{N}(O)H$  radicals formed from 2-oximinopropanoic acid, or 2-oximinopropane by addition of  $R^*$  radicals and rearrangement, react as spin traps for a second  $R^*$  radical. The aminoxyl radicals  $R^1R^2C(R)\dot{N}(O)R$  were very probably formed via an intermediate nitroso compound  $R^1R^2C(R)\dot{N}=O$ . Similar results were obtained when N-tert-butylhydroxylamine was the parent substance.

It has previously been found that aminoxyl radicals, R<sup>1</sup>C  $(=O)-C(R)\dot{N}(O)H-C(=O)R^2$ , are formed by the addition of R' radicals to 1,3-dioxo-2-oximino compounds. 1,2 The hydrogen atom of the aminoxyl group was found to be derived from the oximino group of the parent oxime by rearrangement and migration. In these experiments, the R' radicals were formed from suitable donors by abstraction of a hydrogen atom by photochemically generated 'OH radicals  $(H_2O_2)$  or by the excited state of benzophenone. The coupling constant  $a_{\rm HI}$  was only slightly smaller than  $a_{\rm N}$ , i.e.  $a_{\rm H1} = 1.17 - 1.25$  mT and  $a_{\rm N} = 1.20 - 1.25$  mT. Therefore, the four central lines of the six-line spectra were incompletely resolved, or in several cases formed a superpostion that gave rise to a four-line system with intensities 1:2:2:1. When the reaction was performed in a solvent/donor such as CH<sub>3</sub>OD, the EPR spectrum exhibited 3×3 lines of equal intensity, indicating that the structure of the radicals was R-N(O)D in this case by exchange of protium for deuterium.

It has now been found that R' radicals can be added to a number of other oxime compounds, such as 2-oximinopropanoic acid and 2-oximinopropane, with the formation of aminoxyl radicals R¹R²C(R)N(O)H and R¹R²C(R)N(O)D, i.e. radicals of the same type as observed with 1,3-dioxo-2-oximino compounds.

Furthermore, it was found that a second  $R^*$  radical can be added to the  $R^1R^2C(R)\dot{N}(O)H$  radicals with the formation of aminoxyl radicals of the type  $R^1R^2C(R)\dot{N}(O)R$ . This note describes the results obtained with 2-oximinopropanoic acid and 2-oximinopropane.

# Results and discussion

The experiments were carried out with 2-oximinopropanoic acid, 2-oximinopropane and *N-tert*-butylhydroxylamine.

The coupling constants of the radicals are collected in Table 1.

Figs. 1(a)-(d) show the EPR spectra recorded for the radicals formed in a solution of 2-oximinopropanoic acid dissolved in methanol- $d_4$  together with a small amount of H<sub>2</sub>O<sub>2</sub>, when irradiated with UV light in situ in the EPR cavity. The spectrum of Fig. 1(a) was observed after ca. 3 min of irradiation, and shows a superposition of a four-line system (1:2:2:1) and a  $3\times3$  line system of equal intensity. Evidently, the radical species have the general structure R'N(O)H and R'N(O)D. It was then observed that further irradiation of the sample brought about the appearance of an additional radical species [Fig. 1(b)]. The signal intensity of this new species increased with continued irradiation. Fig. 1(c) is the spectrum recorded after ca. 45 min of irradiation. An extensive change in the spectrum was observed when the UV light was extinguished. Fig. 1(d) shows the spectrum obtained in the dark after about an hour of irradiation. The spectra of the four-line and the 3×3 line systems have disappeared, leaving a high concentration of a 3×5 (1:2:3:2:1) system. It should be pointed out that the concentration of this species increased during the first few minutes in the dark after the UV light had been turned off. The spectrum of Fig. 1(d) was found to be stable for several hours. Evidently, the radical species of the 3×5 line system had the general structure  $R'\dot{N}(O)CD_2OD$ .

Similar results were obtained with 2-oximinopropane dissolved in ethanol/ $H_2O$ , or acetone, together with a small amount of  $H_2O_2$  or benzoyl peroxide, when irradiated with UV light. The spectra exhibited the simultaneous presence of radicals of general structure  $R\dot{N}(O)H$  and  $R\dot{N}(O)CH(CH_3)OH$ , or  $R\dot{N}(O)CH_2C(=O)CH_3$ .

It has previously been shown that aminoxyl radicals of the type R'N(O)H are formed from oximes by the addition of photochemically generated R\* radicals to the C=N bond

Table 1. Parent substances, derived radicals, and their coupling constants in mT.

Parent oxime or hydroxylamine	Solvent/ R-donor	R¹R²C(R)N(O)H or R′N(O)H		R¹R²C(R)N(O)R or R′N(O)R
2-Oximinopropanoic acid	Methanol	$R^1 = CH_3$ ; $R^2 = COO(H)$ $R = CH_2OH$	$a_{\rm N} \simeq a_{\rm H} = 1.27$	$a_{\rm N}=1.46;\ a_{\rm N}=0.93\ ({\rm t})^a$
2-Oximinopropanoic acid	Methanol-d₄	$R^1 = CH_3$ ; $R^2 = COO(H)$ $R = CD_2OD$	$a_{\rm N} = 1.27$ $a_{\rm D} = 0.187$	$a_{\rm N}=1.47;a_{\rm D}=0.143$ (quint)
2-Oximinopropane	Ethanol	$R^1 = R^2 = CH_3$ $R = CH_3CHOH$	$a_{\rm N}\simeq a_{\rm H}=1.27$	$a_{\rm N}=1.46;a_{\rm H}=0.21$ (d)
2-Oximinopropane	Acetone	$R^1 = R^2 = CH_3$ $R = CH_2C(=0)CH_3$	Not observed	$a_{\rm N}=1.29;a_{\rm H}=0.74$ (t)
N-tert-butyl- hydroxylamine	Methanoi	R' = t-Bu $R = CH_2OH$	Not observed	$a_{\rm N}=$ 1.43; $a_{\rm H}=0.49$ (t)
N-tert-butyl- hydroxylamine	Dimethyl sulfoxide	R' = t-Bu $R = CH_3$	$a_{\rm N} = 1.17$ $a_{\rm H} = 1.30$	$a_{\rm N}=1.56;a_{\rm H}=1.25\;{\rm (q)}$

ad = doublet; t = triplet; q = quartet; quint = quintet.

of oximes, followed by migration and rearrangement of the hydrogen atom of the oximino group to be attached to the nitrogen atom<sup>2</sup> [eqn. (1)].

$$R^{1}R^{2}C=NOH + R^{\bullet} \rightarrow R^{1}R^{2}C(R)\dot{N}(O)H$$
 (1)

It is considered that radicals of general type  $R'\dot{N}(O)R$  are formed from  $R'\dot{N}(O)H$  in a radical-driven Fenton reaction, leading to an intermediate nitroso compound 2 that traps R' radicals with the formation fo the aminoxyl radicals 3 [eqns. (2)–(4)].

$$R^{1}R^{2}C(R)\dot{N}(O)H + H_{2}O_{2} \rightarrow R^{1}R^{2}C(R)N(O)H^{+}$$

$$+ \cdot OH + OH^{-}$$
(2)

$$R^{1}R^{2}C(R)N(O)H^{+} \rightarrow R^{1}R^{2}C(R)NO + H^{+}$$
 (3)

$$R^{1}R^{2}C(R)NO + R^{*} \rightarrow R^{1}R^{2}C(R)\dot{N}(O)R$$

$$2$$

$$3$$

$$(4)$$

Alternatively, 2 might be formed in a reaction between 1 and photochemically generated 'OH radicals [eqn. (5)].

$$R^{1}R^{2}C(R)\dot{N}(O)H + \cdot OH \rightarrow R^{1}R^{2}C(R)N = O + H_{2}O \quad (5)$$
1

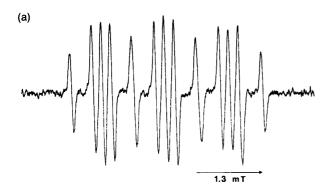
The high yield of the radical species 3 when the UV light was turned off [Fig. 1(d)] seems to support the validity of the reaction path given in eqn. (2). However, the reactions presented in eqns. (2) and (5) might both contribute to the formation of the aminoxyl radicals 3.

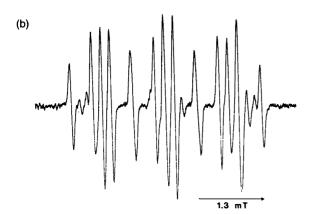
A reaction path that involves rearrangement with migration of one of the groups R<sup>1</sup>, R<sup>2</sup> or R of the compound 1 to the nitrogen atom with the formation of the aminoxyl radical 3 seems to be ruled out by the results of some experiments involving N-tert-butylhydroxylamine. A solution of this substance in methanol together with a small amount of H<sub>2</sub>O<sub>2</sub> gave rise to a spectrum which indicated the formation of the radical t-BuN(O)CH<sub>2</sub>OH with no previous irradiation of the reaction sample with UV light. N-tert-butylhydroxylamine is considered to be oxidized by H<sub>2</sub>O<sub>2</sub> to the corresponding radical t-BuN(O)H, which participates in a radical-driven Fenton reaction to give the nitroso compound t-BuNO, i.e. 2-methyl-2-nitrosopropane and 'OH radicals. The hydroxyl radicals abstract hydrogen atoms from donor compounds, in this case from methanol, with the formation of the short-lived radical 'CH2OH. This radical is trapped by t-BuNO to give the aminoxyl radical t-BuN(O)CH2OH, which is the dominant species in the EPR spectrum, Fig. 2. No radicals of structure t-BuN(OH)CH<sub>3</sub> could be detected, a species that would have been present in the case of migration of one of the methyl groups attached to the central carbon atoms of the parent hydroxylamine.

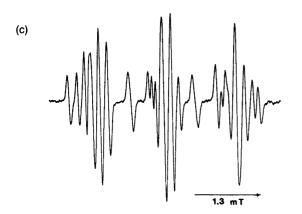
Thus, hydroxyl radicals are formed both by photochemical cleavage of  $H_2O_2$ , and in a radical-driven Fenton reaction [eqn. (2)]. However, it is possible that 'OH radicals are also formed in a conventional Fenton reaction involving iron ions present in small amounts as contaminants of the chemicals and solvent water used.

A detailed account of the trapping of some short-lived radicals by the use of *N-tert*-butylhydroxylamine including the action of small amounts of iron ions, will be given elsewhere.<sup>3</sup>

Table 1 gives the results obtained with 2-oximinopropa-







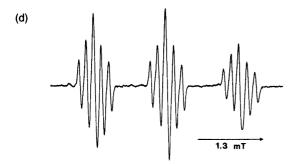


Fig. 1. EPR spectra of the radicals obtained in a solution of  $\mathrm{CH_3C}(=\mathrm{NOH})\mathrm{COOH}$  (50 mM) dissolved in methanol- $d_4$  together with a small amount of  $\mathrm{H_2O_2}$ , when irradiated with UV light: (a) after 3 min of irradiation; (b) after 10 min; (c) after 45 min; (d) in the dark after ca. 1 h of irradiation.

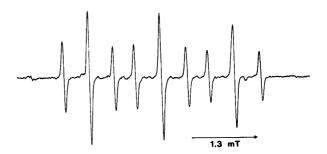


Fig. 2. The EPR spectrum obtained from a solution of *N-tert*-butylhydroxylamine  $\cdot$  HCl 50 mM: dissolved in methanol together with a small amount of  $H_2O_2$ . No irradiation with UV light.

noic acid, 2-oximinopropane and *N-tert*-butylhydroxylamine in some further donor/solvents in addition to those described above. In general, the coupling constants of the aminoxyl radicals are in agreement with those observed in earlier spin-trapping experiments performed with nitroso scavengers such as 2-methyl-2-nitrosopropane. 4-6

Trapping of short-lived radicals of the type  $CH_3\dot{C}HOH$  by use of nitroso compounds such as 2 (i.e.  $R^1 \neq R^2 \neq R$ ) gives rise to aminoxyl radicals which contain two or more chiral centers. Therefore, these aminoxyl radicals exist as diastereomers, the coupling constants of which may differ slightly. However, no structures have been observed, so far, in the EPR spectra of this series which could be associated with pairs of diastereomers.

Conclusions. The experiments have shown that the oxime compounds 2-oximinopropanoic acid or 2-oximinopropane add photochemically generated R' radicals such as 'CH<sub>2</sub>OH or CH<sub>3</sub>CHOH to form aminoxyl radicals, R<sup>1</sup>R<sup>2</sup>C (R)N(O)H. The addition of the second R' radical to the primary aminoxyl radicals gave rise to R<sup>1</sup>R<sup>2</sup>C(R)N(O)R, very probably via an intermediate nitroso compound R<sup>1</sup>R<sup>2</sup>C(R)NO. The results obtained with N-tert-butylhydroxylamine indicated that the reaction did not involve the migration of a methyl group from the central carbon atom to the nitrogen atom. The intermediate nitroso compound is considered to be formed in a radical-driven Fenton reaction.

## **Experimental**

2-Oximinopropanoic acid was prepared as described by Barry and Hartung.<sup>7</sup> 2-Oximinopropane and *N-tert*-butylhydroxylamine · HCl were obtained from Fluka AG and methanol- $d_4$  from Merck.

The preparation of the radicals and the EPR measurements were as described earlier. 1.2

Acknowledgements. The author is indebted to Professor Lennart Eberson for valuable discussions. This work was supported by grants from Adlerbertska Forskningsfonden.

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Received February 20, 1991.