

# Dimerization of Sterically Hindered *p*-Nitrosophenols

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**Abstract**—Dimerization of exhaustively substituted *p*-nitrosophenols was studied by <sup>1</sup>H and <sup>13</sup>C NMR, UV, and IR spectroscopy. The results showed that these compounds in crystal exist as strong dimers having a diazene *N,N'*-dioxide structure. An equilibrium between the dimeric and monomeric forms of nitrosophenols in solution was revealed for the first time.

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Aliphatic nitroso compounds in the crystalline state are known to exist as dimers that have the structure of *cis/trans* isomeric diazene dioxides [1]. Crystalline nitrosobenzenes are pale yellow substances due to formation of dimers; however, in going to organic solvents these dimers quickly dissociate into the corresponding monomeric species, and their solutions are green, which is typical of nitroso compounds. The dissociation of dimers in solution is so fast that its rate cannot be measured [2]. On the other hand, no dimerization is observed for nitrosophenols or nitrosoanilines. It is believed that the monomeric form of these compounds is stabilized due to conjugation between the nitroso group and hydroxy or amino group [3]. Most *p*-nitrosophenols in crystal exist exclusively in the quinone oxime form; by theoretical calculations, the latter was shown to be more thermodynamically stable than the nitrosophenol tautomer [4].

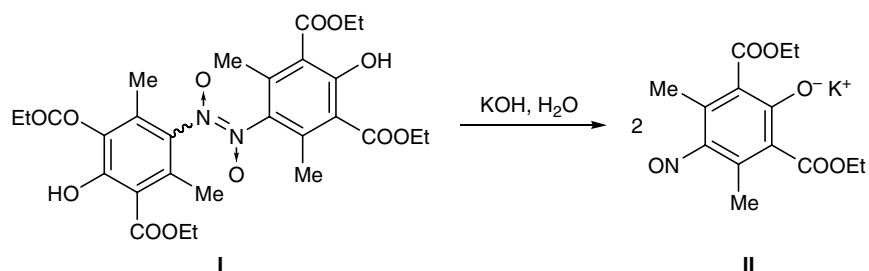
A number of exhaustively substituted nitrosophenols were synthesized and shown to exist exclusively in the nitroso form [5]; upon their dissolution in

aqueous alkali, the color gradually changed from orange to bright green. Taking into account variations in the UV spectra, the authors presumed that dimer **I** undergoes slow dissociation to give two molecules of monomer salt **II** [6] (Scheme 1).

The goal of the present study was to obtain experimental proofs for the dimerization of such phenols using <sup>1</sup>H and <sup>13</sup>C NMR, IR, and UV spectroscopy. For this purpose, we recorded the <sup>1</sup>H NMR spectrum of potassium 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenoxide (**II**) in a 0.1 N solution of KOH in D<sub>2</sub>O, which is bright green and hence monomeric. The spectrum contained a singlet at δ 2.34 ppm (6H) from the methyl groups on the aromatic ring and signals from protons in the ester groups at δ 1.27 (6H, CH<sub>3</sub>, t) and 4.32 ppm (4H, CH<sub>2</sub>, q).

The colorless crystals of the presumed 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenol dimer (**I**) were then dissolved in a 0.1 N solution of KOH in D<sub>2</sub>O to obtain an orange solution of the corresponding potassium salt. The solution continuously changed its

Scheme 1.



color, and it turned emerald green in 1 h. The spectra of the solution were recorded in 5, 7, 10, and 15 min after the dissolution and further until the color and the spectrum no longer changed. In the first spectrum (recorded after 5 min) we observed two signals from the methyl groups on the ring; one of these ( $\delta$  2.11 ppm) was assigned to the dimer, and the other ( $\delta$  2.37 ppm), to the monomer (see figure, a). At that time, the signal from the methyl group of the dimer had greater intensity than the signal from the monomer by a factor of 1.5; in 7 min after the dissolution, the intensities of these signals became similar (see figure, b); finally, the spectrum contained only one methyl proton signal (see figure, c) and fully corresponded to monomeric salt **II**. After 45 min, the conversion of the dimer into monomer was about 95%. Unlike the monomer, the signal from the methyl group in the dimeric nitrosophenol had an asymmetric structure, presumably due to superposition of signals of the *cis*- and *trans*-diazene dioxide isomers.

By measuring the intensity ratio between the methyl proton signals of the monomer and dimer at definite time intervals, we succeeded in plotting a kinetic curve for the dimer consumption. A similar curve was obtained by UV spectroscopy, i.e., by measuring the optical density of a solution of **I** in 0.1 N alkali at  $\lambda$  395 nm, which corresponds to the absorption maximum of monomeric salt **II**.

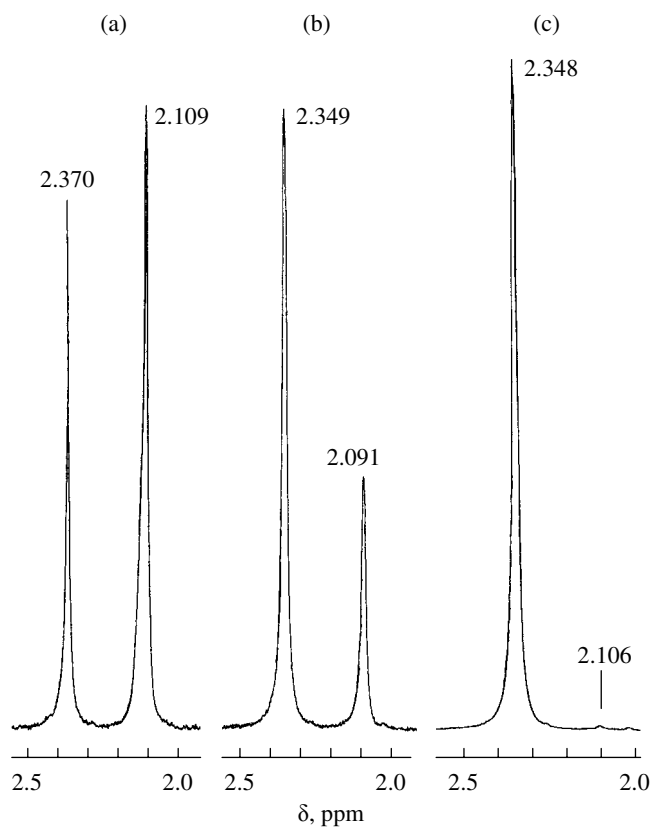
The dissociation of dimer **I** in aqueous alkali is slow; therefore, dimer **I** can be detected experimentally. Presumably, the ionized dimer in aqueous medium is stabilized by hydration. As a rule, both aliphatic and aromatic nitroso compounds are completely insoluble in aqueous and aqueous-alkaline media; therefore, their monomerization process cannot be observed.

We also found that the  $^1\text{H}$  NMR spectrum of a solution of 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenol in chloroform-*d* with a high concentration (0.5 M) contained only one methyl proton signal at  $\delta$  2.51 ppm, which corresponded to the dimer. Lowering the concentration of nitrosophenol **I** to 0.06 M led to the appearance in the spectrum of a signal at  $\delta$  2.76 ppm from the monomeric form. The latter signal becomes predominating upon further dilution. The signal intensities in chloroform-*d* do not change with time, and they depend only on the concentration of nitrosophenol **I**. These findings suggest the existence of equilibrium between the dimer and monomer. By measuring the signal intensity ratios for the methyl

groups of the monomer and dimer at different concentrations of nitrosophenol **I** we estimated the fractions of these forms in solution (see table). Assuming that nitrosophenol **I** in chloroform-*d* gives rise to an equilibrium mixture of the monomer and dimer, we calculated the equilibrium constant  $K_{\text{eq}} = [\text{monomer}]^2 / [\text{dimer}] = 0.016 \pm 0.04$ .

Insofar as the equilibrium constant is fairly low, the monomeric form can be detected only in dilute solutions. This is the reason why the  $^{13}\text{C}$  NMR spectrum of dimer **I** in  $\text{CDCl}_3$  at a concentration of 0.25 to 0.5 M contained only one methyl carbon signal at  $\delta_{\text{C}}$  17.66 ppm. At such a high concentration of **I** the equilibrium is displaced toward the dimeric form so strongly that the signal from the methyl group in the monomer cannot be observed.

Dimerization is unusual for nitrosophenols; it may be rationalized primarily by the fact that these compounds exist exclusively in the nitrosophenol rather than quinone oxime form. This follows from the presence of a strong absorption maximum at  $\lambda$  680 nm in



$^1\text{H}$  NMR spectra recorded during the transformation of 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenol dimer (**I**) into monomer **II** in a 0.1 N solution of KOH in  $\text{D}_2\text{O}$  in (a) 5 min, (b) 8 min, and (c) 1 h after the dissolution.

Ratios of the monomeric and dimeric forms of 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenol, depending on its concentration in  $\text{CDCl}_3$

Total concentration of nitrosophenol <b>II</b> , <sup>a</sup> M	Weight fraction of the monomer	Concentration of the monomer, $c \times 10^3$ M	Concentration of the dimer, $c \times 10^3$ M
0.5	<sup>b</sup>		
0.25	<sup>b</sup>		
0.125	<sup>b</sup>		
0.0625	0.33	20.6	20.9
0.0312	0.41	12.5	9.20
0.0156	0.51	7.96	3.82
0.0078	0.60	4.68	1.56
0.0039	0.66	2.57	0.663
0.00195	0.72	1.40	0.273

<sup>a</sup> Calculated on the monomer.

<sup>b</sup> Not determined because of the low concentration of the monomer.

the electronic spectra in DMF, which corresponds to the  $n-\pi^*$  transition in the nitroso group. Another proof is the presence of two strong absorption bands at 1673 and 1728  $\text{cm}^{-1}$  in the IR spectrum of nitrosophenol **I**; these bands belong to stretching vibrations of the ester carbonyl groups. One carbonyl band is displaced due to formation of a strong intramolecular hydrogen bond with the phenolic hydroxy group, which is possible only for the nitrosophenol tautomer. Likewise, two strong carbonyl bands at 1665 and 1731  $\text{cm}^{-1}$  were observed in the IR spectrum of 2,6-bis(ethoxycarbonyl)-3-methyl-5-phenyl-4-nitrosophenol (**III**).

Nevertheless, the existence of only nitrosophenol tautomers of the compounds under study cannot be regarded as the only factor responsible for their dimerization. Some *p*-nitrosophenols having one acyl or alkoxycarbonyl group in the *ortho* position with respect to the hydroxy group are known to exist exclusively in the monomeric form (their crystals are green), despite their nitrosophenol structure [6]. On the other hand, steric hindrances in substituted nitrosobenzene molecules favor increased fraction of the corresponding dimer in solution [7]. Therefore, we believe that steric hindrances in exhaustively substituted nitrosophenol **I** and its analogs (e.g., in nitrosophenol **III** which is also capable of undergoing dimerization) disrupt conjugation between the hydroxy and nitroso groups; as a result, their dimerization in solution and in the crystalline state becomes possible.

## EXPERIMENTAL

The  $^1\text{H}$  NMR spectra were recorded on a Bruker Avance 200 spectrometer (Krasnoyarsk Regional Center, Siberian Division, Russian Academy of Sciences) from solutions in  $\text{CDCl}_3$  or in a 0.1 N solution of KOH in  $\text{D}_2\text{O}$ . The IR spectra were measured on a SpecTRA TECH InspecIR IR microscope based on an Impact 400 spectrometer with Fourier transform. A sample was placed on a gilded plate and rolled out with a roller knife, the plate was placed on the microscopic stage, and the attenuated total reflection (ATR) spectrum was recorded (MST/A detector, Si Caplugs lens; wave number range 4000 to 650  $\text{cm}^{-1}$ ; resolution 1.928  $\text{cm}^{-1}$ ; scan number 64; OMNIC 5.1 E.S.P. software). The UV spectra were obtained on an SF-26 spectrophotometer using 1-cm quartz cells maintained at 25°C; the concentration of nitrosophenol **I** was  $1 \times 10^{-5}$  M in 0.1 N sodium hydroxide or  $1 \times 10^{-2}$  M in dimethylformamide.

**Potassium 2,6-bis(ethoxycarbonyl)-3,5-dimethyl-4-nitrosophenoxide (II)**. Isonitrosoacetylacetone, 0.65 g (5 mmol), and diethyl 3-oxopentanedioate, 2 g (10 mmol), were added to a solution of 0.28 g (5 mmol) of potassium hydroxide in 5 ml of anhydrous ethanol. The mixture was kept for 20 min at 18–20°C, and anhydrous diethyl ether was added until the mixture turned turbid. The precipitate was filtered off and dried over  $\text{Na}_2\text{SO}_4$  under reduced pressure. Yield 1 g (68%), bright green crystals.  $^1\text{H}$  NMR spectrum (0.1 N KOH in  $\text{D}_2\text{O}$ ),  $\delta$ , ppm: 1.27 t (6H,  $\text{CH}_3$ ), 2.34 s (6H,  $\text{CH}_3$ ), 4.32 q (4H,  $\text{CH}_2$ ).

**Diethyl 2-hydroxy-4,6-dimethyl-5-nitrosobenzene-1,3-dicarboxylate dimer (I)**. A solution of 1 g of potassium salt **II** in 4 ml of water was acidified with dilute hydrochloric acid (1:3). On oily material separated and quickly solidified. Yield 0.75 g (51%), colorless crystals, mp 106°C; published data [8]: mp 101°C.  $^1\text{H}$  NMR spectrum ( $\text{CDCl}_3$ ),  $\delta$ , ppm: 1.46 t (6H,  $\text{CH}_3$ ), 2.51 s (6H,  $\text{CH}_3$ ), 4.49 q (4H,  $\text{CH}_2$ ), 11.98 s (1H, OH).  $^{13}\text{C}$  NMR spectrum ( $\text{CDCl}_3$ ),  $\delta_c$ , ppm: 14.13 ( $\text{CH}_2\text{CH}_3$ ), 17.66 ( $\text{CH}_3$ ), 62.32 ( $\text{OCH}_2$ ), 117.75 ( $\text{C}^1$ ,  $\text{C}^3$ ), 137.50 ( $\text{C}^4$ ,  $\text{C}^6$ ), 145.99 ( $\text{C}^5$ ), 160.35 ( $\text{C}^2$ ), 168.17 ( $\text{C}=\text{O}$ ).  $^1\text{H}$  NMR spectrum of the monomer ( $\text{CDCl}_3$ ),  $\delta$ , ppm: 1.45 t (6H,  $\text{CH}_3$ ), 2.76 s (6H,  $\text{CH}_3$ ), 4.53 q (4H,  $\text{CH}_2$ ), 12.53 s (1H, OH).

**Potassium 2,6-bis(ethoxycarbonyl)-3-methyl-4-nitroso-5-phenylphenoxide (III)** was synthesized as described above for salt **II** from 0.28 g (5 mmol) of potassium hydroxide in 5 ml of anhydrous ethanol,

0.95 g (5 mmol) of isonitrosobenzoylacetone, and 2 g (10 mmol) of diethyl 3-oxopentanedioate. Yield 0.5 g (28%). Yield of the corresponding dimer (isolated as described above for dimer I) 0.21 g (12%), pale yellow crystals, mp 101–102°C (105°C [8]).

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