

Nucleophilic Aromatic Substitution of Hydrogen in the Reaction of *tert*-Alkylamines with Nitrosobenzenes – Synthesis and NMR Study of *N*-(*tert*-Alkyl)-*ortho*-nitrosoanilines

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The reaction of primary amines bearing tertiary alkyl groups (e.g. R-NH₂; R = *t*Bu, 1-adamantyl) with nitrosobenzenes has been found to proceed by oxidative nucleophilic aromatic substitution of hydrogen, thereby affording *N*-(*tert*-alkyl)-*ortho*- and -*para*-nitrosoanilines. The replacement of hydrogen proceeds more rapidly than the replacement of *ortho*- or *para*-nitro or -bromo substituents. With *p*-nitronitrosobenzene, both *ortho*-hydrogen atoms are

substituted to afford *N,N'*-di(*tert*-alkyl)-4-nitro-2-nitroso-1,3-phenylenediamines **8a,b**. The addition of oxidizing agents (e.g. MnO₂) increases the yield of products. ¹H-, ¹³C-, ¹⁴N- and ¹⁵N-NMR studies have confirmed the structures of the compounds under investigation. In *ortho*-nitrosoanilines, the rotamer with the nitroso group *syn* to the amino group is favored.

Introduction

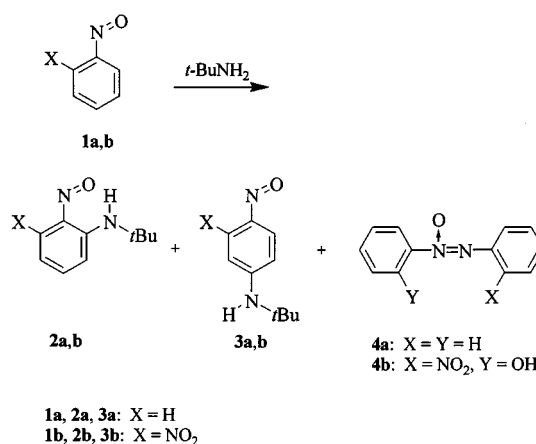
As a rule, amines attack nitrosobenzenes at the N atom of the nitroso group^[1a]. Thus, reaction of primary amines R-NH₂ (R = Me, Et, CH₂Ph) with nitrosobenzene in CHCl₃ as solvent yields alkylphenyldiazenes. *tert*-Butylamine does not react under such conditions.^[2] In some cases, amines can displace nucleofugal groups (e.g. OH, OR, NH₂, NHR) in nitrosobenzenes at the position *para* to the nitroso group (S_NAr reactions). Transamination of *para*-nitrosoanilines provides an example of such a reaction.^[1b] We have not been able to find any references to reactions of nitrosobenzenes with amines, or with other nucleophiles, which might proceed by nucleophilic aromatic substitution of hydrogen (S_NAr^H reactions).

We wish to report that the reaction of nitrosobenzenes with primary amines bearing a tertiary alkyl group (i.e. $R-NH_2$; $R = tBu$, 1-adamantyl) in aprotic dipolar solvents proceeds through nucleophilic aromatic substitution of hydrogen to afford *N*-(*tert*-alkyl)-*ortho*- and -*para*-nitrosoanilines. The aim of the work described herein was to investigate this novel reaction.

Results and Discussion

The reaction of nitrosobenzene (**1a**) with *tert*-butylamine was found to proceed in an unusual manner, compared with the corresponding reactions with other primary amines, e.g. MeNH₂ or EtNH₂. The nitroso group remained intact and the amine replaced hydrogen at a position *ortho* or *para* to

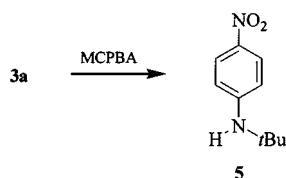
the nitroso group to afford *N*-(*tert*-butyl)-*o*-nitrosoaniline (**2a**) and *N*-(*tert*-butyl)-*p*-nitrosoaniline (**3a**) in a combined yield of ca. 30%.^[3] Azoxybenzene (**4a**) was also generated in this reaction in ca. 60% yield (Scheme 1, Table 1).



Scheme 1

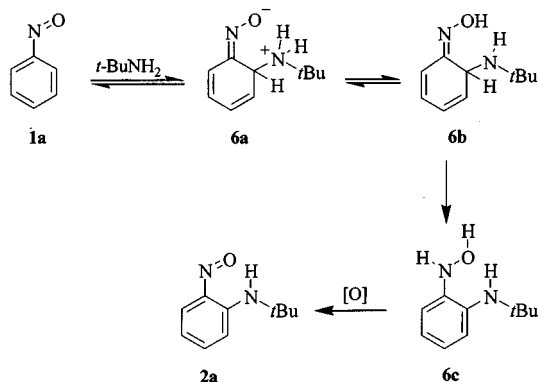
Compound **2a** was obtained as a low-melting brown solid, and was found to be rather stable at room temperature. Its structure will be discussed below. In contrast, the yellow *para*-substituted compound **3a** proved to be unstable in the absence of a solvent, although in solution (CH₂Cl₂, benzene) it could be stored for several days with practically no decomposition. The stability of **3a** was enhanced by the presence of a small amount of hydrochloric acid. The ¹H- and ¹³C-NMR spectra of **3a** resemble those of *N*-methyl-*p*-nitrosoaniline.^[4] The structure of **3a** was further confirmed by its oxidation to the stable nitro derivative **5**. It is noteworthy that attempts to synthesize **3a** by the Fisher–Hepp reaction were unsuccessful.^[5a,5b]

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Scheme 2

The reaction of *tert*-butylamine with nitrosobenzene can be considered as an oxidative nucleophilic substitution of hydrogen,^[6] involving nucleophilic attack of *t*BuNH₂ at the *ortho* position of nitrosobenzene to give first the σ_H adduct **6a** and then the oxime **6b**. This oxime is subsequently oxidized by a second molecule of nitrosobenzene to yield **2a** and phenylhydroxylamine. The latter, in turn, couples with nitrosobenzene to afford azoxybenzene (**4a**). One can envisage the *para*-substituted compound **3a** being formed in a similar way.



Scheme 3

We suggest that the transformation of oxime **6b** into the nitroso compound **2a** could proceed in two stages, the first being the tautomerization of oxime **6b** to give intermediate hydroxylamine **6c**, and the second being the oxidation of **6c** to nitroso compound **2a**. If this is the case, the rearomatization step should be the result of proton transfer in the **6b** $\rightarrow$ **6c** tautomerization, in contrast to well-known S_NAr^H reactions in the nitroaromatic series, where the rearomatization step is the result of an oxidation process.^[6a,6b]

The reason why *t*BuNH₂ does not attack the nitrogen atom of the nitroso group to give azo compounds is not quite clear. It is noteworthy that the Mg salt of *tert*-butylamine reacts readily with the nitroso group of nitrosobenzene to afford an azo compound.^[7]

The rate of the reaction of *t*BuNH₂ with nitrosobenzene depends strongly on the solvent used. The reaction proceeds much faster in DMSO than in CH₃CN. In non-polar solvents (benzene) and in hydroxy solvents (EtOH) it does not take place at all. It should be noted that the reaction only reaches completion when excess *t*BuNH₂ is used. In our experiments we used a threefold excess of *t*BuNH₂. In this connection, it seems plausible that stages of the reaction mechanism **1a** $\rightarrow$ **6a** $\rightarrow$ **6b** (Scheme 3) are reversible and that the transformation **6b** $\rightarrow$ **6c** is a base-catalyzed process.

The reaction also proceeded successfully when *t*BuNH₂ was used as solvent. In this case, *ortho*-substituted **2a** was produced almost exclusively, whereas in CH₃CN or DMSO the predominant product was the *para*-substituted isomer **3a** (see Table 1).

The reaction of substituted nitrosobenzenes was also investigated. *o*-Nitronitrosobenzene (**1b**, Scheme 1) was found to react much faster than nitrosobenzene. In CH₃CN, this reaction reached completion within 2 h at room temperature. The *ortho*-substituted isomer **2b** was the principal product. The product of nitro-group displacement, i.e. **2a**, was not observed.

The introduction of a nitro group on the aromatic ring has contrasting influences on the stabilities of *ortho*- and *para*-nitrosoanilines. Whereas the *ortho* compound **2b** becomes more stable and can be stored at room temperature for a long time, the stability of the *para* product **3b** decreases. It could be separated from the other isomer by chromatography, but partly decomposed to give a tar on concentrating the solution. Its structure was confirmed solely on the basis of mass-spectrometric data.

The azoxy compound **4b** formed in this reaction was found to be 2-hydroxy-2'-nitroazoxybenzene. This compound was shown by Bamberger et al.^[8] to be the normal product of condensation of *o*-nitrophenylhydroxylamine with *o*-nitronitrosobenzene. Interpretation of NMR data (see Experimental Section) showed the hydroxy group in **4b** to be located on the ring, and connected with the *N*-oxide nitrogen atom of the azoxy group.

The important aspect of the reaction under investigation is the regioselectivity of the nucleophilic attack at the *ortho* versus the *para* position relative to the nitroso group. The directing effect of the NO₂ group at the *ortho* position is usually accounted for in terms of intramolecular hydrogen bonding in the zwitterionic σ adduct.^[6c] The same explanation could be invoked to account for the predominant formation of the *ortho*-substituted compound **2b** from nitronitrosobenzene **1b**. However, in the case of nitrosobenzene **1a**, the *para*-substituted isomer **3a** was predominant when the reaction was carried out in the same solvent. Thus, it is apparent that the problem of regioselectivity in the nitrosobenzene series is rather complicated and a thorough investigation of the reaction mechanism is required.

p-Nitronitrosobenzene (**1c**) underwent coupling with *t*BuNH₂ to afford the *ortho*-substituted compound **2c**. The product of *para* substitution, i.e. **3a**, which might have resulted from a nucleophilic displacement of nitro group, was not detected.

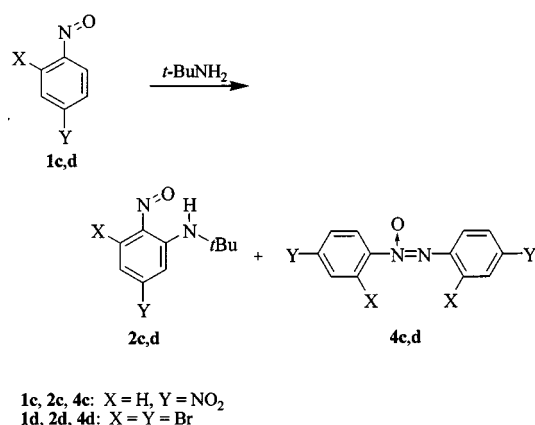
When 2,4-dibromonitrosobenzene (**1d**) was treated with *t*BuNH₂, substitution of hydrogen took place, but not the displacement of a bromine atom. The latter reaction did, however, occur with 2,4,6-tribromonitrosobenzene (**7**), albeit much more slowly (Scheme 5). It is noteworthy that the N=O group also remained intact in this reaction. Both reactions yielded the same *ortho*-substituted compound **2d**.

In conclusion, it can be stated that substitution of the ring hydrogen atom (S_NAr^H reaction) is preferred to the

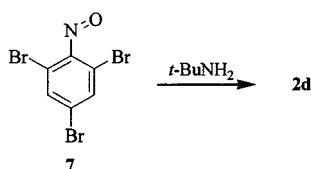
Table 1. Reaction of nitroso compounds **1a–d** and **2c** with *tert*-butylamine (CH₃CN as solvent, unless stated otherwise)

No.	Substrate	Temp. [°C]	Time [h]	Oxidant	Products (yield, %)		
1	1a	20	144	—	2a (6)	3a (17)	4a (39)
2 ^[a]	1a	20	50	—	2a (10)	3a (22)	4a (62)
3 ^[b]	1a	20	29	—	2a (27)	3a (< 1)	4a (50)
4	1b	20	4	—	2b (26)	3b (6) ^[c]	4b (60)
5	1b	20	0.5	MnO ₂	2b (55)	3b (11) ^[c]	4b (19)
6	1b	20	1.7	DMAAD	2b (13)	3b (5) ^[c]	4b (14)
7	1c	40	1.2	—	2c (27)	—	4c (34)
8	1c	20	2.5	MnO ₂	2c (70)	—	4c (< 5)
9	1c	20	1.4	DMAAD	2c (92)	—	4c (< 5)
10	1c	40	0.5	NBS	2c (74)	—	4c (< 5)
11	1c	20	72	—	8a (10)	—	—
12	1c	60	5	MnO ₂	8a (81)	—	—
13	1d	45	1	—	2d (29)	—	4d (36)
14	2c	40	1.3	—	8a (23)	—	—
15	2c	20	23	DMAAD	8a (55)	—	—

^[a] DMSO as solvent. — ^[b] The reaction was carried out without solvent. — ^[c] A tentative yield of **3b** as it decomposed on concentrating the solution.



Scheme 4



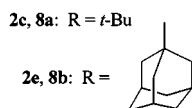
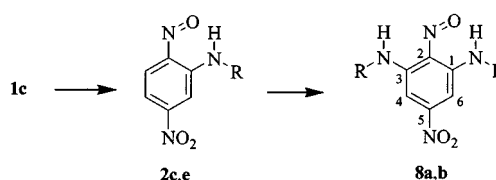
Scheme 5

substitution of nucleofugal groups, e.g. NO₂ and Br (S_NAr reaction), in the nitrosobenzene series. This observation is consistent with Makosza's generalization,^[6d] that intermediate σ_H adducts are formed more rapidly than σ_X adducts. It should be noted that nucleophilic substitution in nitronitrosobenzenes **1b,c** takes place *ortho* to the nitroso and not *ortho* to the nitro group. This regioselectivity can be attributed to the high stability of intermediate oximes of the type **6b** (see Scheme 3).

To increase the yield of *N*-(*tert*-butyl)nitrosoanilines, the reaction of nitrosobenzenes with *t*BuNH₂ was carried out in the presence of an oxidant. The results are summarized in Table 1. The yield of **2b** increased to a maximum (55%) when MnO₂ was employed, while that of azoxy compound **4b** decreased to 19% under these conditions. The yield of

2c became almost quantitative when the bis(*N,N*-dimethylamide) of azodicarboxylic acid (DMAAD) was used (Table 1). It was used in analogy to diethyl azodicarboxylate, which is known to oxidize hydroxylamines to nitroso compounds, but could not be used here as it reacts with *t*BuNH₂. The use of MnO₂ or *N*-bromosuccinimide resulted in good yields of **2c**. The bromination of *t*BuNH₂ with NBS is very fast, hence the actual oxidant of the intermediate hydroxylamine is likely to be *N*-bromo-*tert*-butylamine.

o-(*tert*-Butylamino)-substituted nitrosobenzene **2c**, bearing the strongly electron-withdrawing nitro group in the *para* position, underwent further displacement of hydrogen with excess *t*BuNH₂ to afford the diamine **8a** (Scheme 6). It was obtained in 10% yield directly from *p*-nitronitrosobenzene (**1c**), and in 81% yield using MnO₂ (Table 1).



Scheme 6

We extended this reaction to another primary amine of similar structure, namely 1-adamantylamine. In DMSO as solvent, the reaction of **1c** proceeded in the expected manner, to give *ortho*-substituted compound **2e** in 29% yield. As already mentioned, a high base concentration in the reaction medium is necessary for the reaction to proceed rapidly. As the solubility of 1-adamantylamine is limited, pyridine was added to accelerate the reaction (see Table 2).

The disubstituted compound **8b** was successfully obtained from **2e** when MnO₂ was used as an oxidant. This

Table 2. Reaction of nitroso compounds **1c** and **2e** with 1-adamantylamine (DMSO as solvent)

No.	Substrate	Temp. [°C]	Time [h]	Oxidant	Products (yield, %)	
1	1c	40	5.5	—	2e (29)	4c (54)
2	1c	40	2.5	MnO ₂	2e (65)	4c (15)
3 ^[a]	1c	40	2	—	2e (26)	4c (55)
4 ^[a]	1c	60	8	MnO ₂	8b (59)	—
5	2e	60	15	MnO ₂	8b (38)	—

^[a] The reaction was carried out in the presence of a 10-mol excess of pyridine.

compound could also be obtained in 59% yield starting from **1c**. Addition of pyridine also accelerated this reaction (see Table 2).

NMR Study of *ortho*-Nitrosoanilines

The structures of the compounds under investigation were confirmed by NMR spectrometry. All resonances in the ¹H- and ¹³C-NMR spectra were unambiguously assigned with the help of special procedures, including NOESY and CH COSY (see notes to Table 3). Some of the nitrosoanilines were also studied by ¹⁴N- and ¹⁵N-NMR spectroscopy. The ¹⁴N-NMR spectrum of **2a** showed a broad signal due to the nitroso group at $\delta = 397$, and an amino group signal at $\delta = -284$, both of which are typical for these groups.^[9] The ¹⁴N signal of the nitroso group in **2b** was unobservably broad, but was clearly detected in the ¹⁵N-NMR spectrum at $\delta = 375.3$. The ¹⁵N signal of the NH-*t*Bu group was readily detected by polarization transfer from the N-H proton to the ¹⁵N nucleus. The values of the coupling constants ¹J(¹H, ¹⁵N) in **2a–d** decreased in the range 90–95 Hz, which is typical for amines.^[9] This demonstrates that these compounds are indeed the nitroso compounds, and not the quinone oxime isomers.

The ¹³C-NMR data of nitrosoanilines listed in Table 3 merit some comments. It has previously been reported that in nitrosobenzenes bearing an *ortho* substituent (e.g. CH₃^[4b] or NO₂^[10]), the rotamer having the N=O group *anti* to the substituent is favored because of steric effects. In our case, two rotamers **A** and **B** can a priori be envisaged, in which the N=O group is arranged *syn* to the amino group as in **A**, or *anti* as in **B**. These rotamers would give rise to discrete sets of ¹³C-NMR signals, where the shifts of carbon atoms C-1 and C-3 *ortho* to the N=O group would differ most markedly because of the large anisotropy of this function. For example, *N,N*-dimethyl-*p*-nitrosoaniline (**9**), in which rotation of the N=O group is completely restricted at low temperatures on the NMR timescale, exhibits a chemical-shift difference of ca. 30 ppm between C-3 and C-5.^[11]

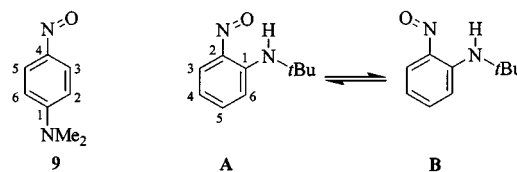
The ¹H- and ¹³C-NMR spectra of *ortho*-nitrosoanilines lacking a substituent at the 3-position (**2a,c,e**) are temperature-dependent (see notes to Table 3). At room temperature, the C-1 and C-3 signals, as well as the 3-H signal are broadened, indicating that rotation of the N=O group takes

Table 3. ¹³C-NMR chemical shifts^[a] (δ values, calculated δ in parentheses) of **2a–e** and **8a–b** in CDCl₃ at 297 K (*dynamic broadening is observed)

	2a ^[b,c]	2b	2c ^[d]	2d	2e ^[e]	8a ^[f]	8b ^[g]
C-1	135.1 (128.0)	134.5	133.2*	136.0	134.3*	137.4	137.5
C-2	156.7 (158.7)	146.3	154.8	151.0	155.2	146.2	146.1
C-3	141.4 (141.8)	157.4	144.3*	138.8	141.8*	153.1	152.7
C-4	115.7 (114.1)	108.8	109.1	123.4	109.0	91.2	91.6
C-5	137.2 (133.3)	136.7	150.3	132.7	150.7	155.4	155.0
C-6	116.2 (110.6)	120.8	113.5	119.3	114.2	94.4	94.9
Me	29.1	28.4	29.2	29.5		29.49, 29.53	
CMe ₃	51.3	52.4	52.0	52.0		52.0, 52.3	

^[a] Assignments were made using the following procedures: 2D CH COSY (for **2a**), proton-coupled spectroscopy (for **2d** and **8a**), selective proton decoupling (for **2a–e**), NOESY (for **2a,b** and **8a**), selective polarization transfer (for **2b–d** and **8a**), APT (for **8a,b**). —

^[b] The spectra were obtained at 243 K (the signals of C-1 and C-3 are broadened at 297 K). — ^[c] The calculations were based on the chemical shifts of *N,N*-dimethyl-*para*-nitrosoaniline **9**^[11] (CDCl₃, at 213 K): $\delta = 110.63$ (C-2 and C-6), 109.74 (C-3), 142.06 (C-5), 155.20 (C-1), 162.59 (C-4). — ^[d] The spectra were obtained at 243 K. — ^[e] For the adamantyl group of **2e**: $\delta = 29.35, 35.99, 42.11, 53.14$. — ^[f] At 333 K, signals due to C-1 and C-3 were not observed owing to broadening. — ^[g] For the adamantyl group of **8b**: $\delta = 29.40, 29.57, 36.25, 36.12, 42.15, 42.17, 53.11, 53.26$.



Scheme 6

place, while at low temperatures all signals are sharp indicating the presence of only one rotamer in the solution. In **2b,d**, as well as in **8a,b**, all the signals are well-resolved even at room temperature.

The ¹³C-chemical shifts of *ortho*-nitrosoanilines were estimated using additivity rules.^[12] The shifts of **9** were taken as a basis for the calculations. As an illustration, the calculated data for **2a** are given in Table 3. Although this method is not particularly precise, we can unambiguously state that in all the *ortho*-nitrosoanilines investigated, the N=O group is *syn* to the amino group, as in rotamer **A**. This rotamer is presumably favored because of intramolecular hydrogen bonding.

The unusually low-field signal in the range $\delta = 11–12$ in the ¹H-NMR spectra of **2a–e** can be assigned to the NH proton chelated by the N=O group. The disubstituted compounds **8a,b** showed two signals due to NH protons at $\delta = 12.8$ and at $\delta = 7.7$. The former signal can be assigned to the chelated NH proton. Selective polarization transfer from these protons allowed the assignment of the C-4 and C-6 signals in **8a,b**. The dynamic broadening at elevated temperatures was taken into consideration in assigning the C-1 and C-3 signals.

In conclusion, it should be noted that the synthesis of *N*-substituted *ortho*-nitrosoanilines is rather problematic.^[1b,13]

Only a few examples of this class of compounds are known.^[14] The described reactions could offer a new access to compounds of this type.

Experimental Section

General: Melting points are uncorrected. *o*-Nitronitrosobenzene,^[8] *p*-nitronitrosobenzene,^[15] 2,4-dibromonitrosobenzene,^[16] 2,4,6-tribromonitrosobenzene,^[17] mercury(II) trifluoroacetate,^[18] MnO₂,^[19] and bis(*N,N*-dimethylamide) of azodicarboxylic acid (DMAAD)^[20] were prepared according to published procedures. All other reagents were purchased from commercial sources. – NMR spectra were recorded with a Bruker AM 300 instrument at 298 K unless otherwise stated; chemical shifts are δ values downfield from internal TMS (¹H, ¹³C) or external CH₃NO₂ (¹⁴N, ¹⁵N). – Mass-spectral data were obtained at 70 eV by electron impact.

Reaction of Nitrosobenzene (1a) with *tert*-Butylamine

(A) In Acetonitrile: *t*BuNH₂ (0.2 mL, 9.75 mmol) was added to a stirred solution of **1a** (0.35 g, 3.25 mmol) in CH₃CN (2 mL). After the reaction was complete (Table 1), the solvent was removed in vacuo, the residue was dissolved in diethyl ether (20 mL), and the resulting solution was extracted with 50 mL of 5% aqueous hydrochloric acid. The ethereal extract was dried (MgSO₄) and the solvent was removed in vacuo. The residue was crystallized to give azoxybenzene (**4a**) (125 mg), m.p. 35–37°C (benzene), identical with an authentic sample. The aqueous acidic solution was partly neutralized with 5.6 g of Na₂CO₃ and then extracted with diethyl ether. The solvent was removed in vacuo from the organic phase and the residual oil was chromatographed (silica gel, eluent benzene/diethyl ether, 5:1) to yield **2a** (75 mg) and **3a** (5 mg). The remaining aqueous acidic solution was then completely neutralized with Na₂CO₃ and extracted with further diethyl ether to give, after chromatographic separation, additional portions of **2a** (10 mg) and **3a** (30 mg).

***N-tert*-Butyl-2-nitrosobenzene (2a):** Brown crystals, m.p. 39–41°C (pentane). – UV (CH₃OH): $\lambda_{\max}$ (lg ϵ) = 228 nm (4.35), 302 (3.99), 472 (3.79). – ¹H NMR (CDCl₃, 243 K): δ = 1.46 (s, 9 H, *t*Bu), 6.88 (dd, *J* = 7.5, 7.3 Hz, 1 H, 4-H), 7.05 (d, 1 H, *J* = 8.9 Hz, 6-H), 7.34 (ddd, *J* = 8.9, 7.5, 1.7 Hz, 1 H, 5-H), 8.59 (d, *J* = 7.3 Hz, 1 H, 3-H), 12.05 (s, 1 H, NH); at 298 K the signal of 3-H is broadened. – ¹⁴N NMR (CDCl₃, 323 K): δ = –284 ($\Delta\nu_{1/2}$ = 750 Hz, NH), 397 ($\Delta\nu_{1/2}$ = 2000 Hz, N=O). – ¹⁵N NMR, INEPT (CDCl₃): δ = –282.5 (*J* = 94.7 Hz, NH). – MS (70 eV); *m/z*: 178 [*M*⁺]. – C₁₀H₁₄N₂O (178.2): calcd. C 67.38, H 7.92, N 15.72; found C 67.77, H 7.39, N 15.81.

***N-tert*-Butyl-4-nitrosoaniline (3a):** Deep-yellow oil. – ¹H NMR ([D₆]DMSO, 403 K): δ = 1.40 (s, 9 H), 6.77 (d, 2 H, *J* = 8.2 Hz), 7.59 (d, 2 H, *J* = 8.2 Hz); at 298 K all the signals are broadened. – ¹³C NMR ([D₆]DMSO, 403 K): δ = 28.4, 50.8, 112.0 (broadened at 298 K), 124.2 (not detected at 298 K due to broadening), 154.1, 162.6. – MS (70 eV); *m/z*: 178 [*M*⁺].

(B) In DMSO: *t*BuNH₂ (0.2 mL, 9.75 mmol) was added to a stirred solution of nitrosobenzene (**1a**) (0.35 g, 3.25 mmol) in DMSO (1 mL). After the reaction was complete (see Table 1), the reaction mixture was poured into water (10 mL) and extracted with diethyl ether. The products were separated as described above to give **2a** (58 mg), **3a** (128 mg) and **4a** (200 mg).

(C) Without Solvent: Nitrosobenzene (**1a**, 0.3 g, 3.25 mmol) was added to stirred *t*BuNH₂ (5 mL). After the reaction was complete (see Table 1), the excess *t*BuNH₂ was removed in vacuo and the

products were separated as described above to give **2a** (150 mg), **3a** (5 mg) and **4a** (140 mg).

Reaction of *o*-Nitronitrosobenzene (1b) with *tert*-Butylamine: *t*BuNH₂ (0.2 mL, 2.75 mmol) was added to a stirred solution of **1b** (0.49 mg, 3.25 mmol) in acetonitrile (2 mL). After the reaction was complete (see Table 1), the solvent was removed in vacuo, and the residue was passed through a short column of silica gel, eluting with benzene. The eluate was concentrated to dryness and the solid residue was extracted with hexane. The residue after extraction was identified as **4b** (280 mg). The solvent was removed from the hexane solution and the residue was chromatographed (silica gel, eluent benzene) to yield **2b** (187 mg) and **3b** (43 mg).

***N-tert*-Butyl-3-nitro-2-nitrosoaniline (2b):** Black crystals, m.p. 108–112°C (hexane). – IR (KBr): $\tilde{\nu}$ = 1370 cm^{–1}, 1550 (NO₂). – UV (CH₃OH): $\lambda_{\max}$ (lg ϵ) = 215 nm (4.55), 228 (4.77), 300 (4.15), 465 (4.24). – ¹H NMR (CDCl₃): δ = 1.49 (s, 9 H, *t*Bu), 6.98 (d, 1 H, *J* = 7.2 Hz, 6-H), 7.30 (d, 1 H, *J* = 9.2 Hz, 4-H), 7.45 (dd, 1 H, *J* = 9.2, 7.2 Hz, 5-H), 11.9 (s, 1 H, NH). – ¹⁴N NMR (CDCl₃): δ = –276 ($\Delta\nu_{1/2}$ = 900 Hz, NH), –9 ($\Delta\nu_{1/2}$ = 200 Hz, NO₂). – ¹⁵N NMR (CDCl₃): δ = –277.4 (NH), –9.2 (NO₂), 375.3 (NO). – ¹⁵N NMR, INEPT (CDCl₃): δ = –277 (*J* = 91.4 Hz, NH). – MS (70 eV); *m/z*: 223 [*M*⁺]. – C₁₀H₁₃N₃O₃ (223.2): calcd. C 53.81, H 5.87, N 18.82; found C 54.04, H 5.44, N 18.92.

***N-tert*-Butyl-3-nitro-4-nitrosoaniline (3b):** The eluate from the aforementioned chromatographic separation was concentrated to a small volume at 0°C, CCl₄ was added, and the resulting solution was analyzed by mass spectrometry. – MS (70 eV); *m/z*: 223 [*M*⁺].

1-(2-Hydroxyphenyl)-2-(2'-nitrophenyl)diazene 1-Oxide (4b): Bright-yellow crystals, m.p. 46.5–48.5°C (benzene) (ref.^[8] m.p. 48–49°C). – IR (KBr): $\tilde{\nu}$ = 1360 cm^{–1}, 1520 (NO₂). – ¹H NMR (CDCl₃): δ = 6.93 (dd, 1 H, *J* = 8.5, 7.2 Hz, 5-H), 7.08 (d, 1 H, *J* = 8.4 Hz, 3-H), 7.44 (dd, 1 H, *J* = 8.4, 7.2 Hz, 4-H), 7.46 (dd, 1 H, *J* = 7.3, 8.2 Hz, 4'-H), 7.60 (d, 1 H, *J* = 8.0 Hz, 6'-H), 7.66 (dd, 1 H, *J* = 7.3, 8.0 Hz, 5'-H), 8.05 (d, 1 H, *J* = 8.2 Hz, 3'-H), 8.12 (d, 1 H, *J* = 8.5 Hz, 6-H), 11.22 (s, 1 H, OH). – ¹³C NMR (CDCl₃): δ = 119.5 (C-3), 119.7 (C-5), 123.9 (C-6), 124.99 (C-3'), 125.02 (C-6'), 128.8 (C-4'), 131.6 (C-1), 134.0 (C-5'), 135.0 (C-4), 136.1 (C-1'), 143.0 (C-2'), 153.5 (C-2); the assignment was made with the aid of ¹³C{¹⁴N, ¹H} NMR spectra, CH and HH COSY, and the APT procedure. – ¹⁴N NMR (CDCl₃): δ = –47 ($\Delta\nu_{1/2}$ = 280 Hz, N(O)=), –12 ($\Delta\nu_{1/2}$ = 220 Hz, NO₂). – MS (70 eV); *m/z*: 259 (100) [*M*⁺], 258 (90), 243 (30). – C₁₂H₉N₃O₄ (259.1): calcd. C 55.60, H 3.50, N 16.21; found C 55.39, H 3.87, N 16.15.

Reaction of *p*-Nitronitrosobenzene (1c) with *tert*-Butylamine: The coupling of *t*BuNH₂ with **1c** was carried out according to the above procedure to afford **2c** (see Table 1) and bis(4-nitrophenyl)diazene *N*-oxide **4c**, m.p. 199–200°C (ref.^[8] m.p. 200°C), identical to an authentic sample.

***N-tert*-Butyl-5-nitro-2-nitrosoaniline (2c):** Red crystals, m.p. 69–72°C. – IR (KBr): $\tilde{\nu}$ = 1340 cm^{–1}, 1540 (NO₂). – UV (CH₃OH): $\lambda_{\max}$ (lg ϵ) = 222 nm (4.23), 247 (4.24), 300 (4.07), 495 (3.84). – ¹H NMR (CDCl₃): δ = 1.54 (s, 9 H, *t*Bu), 7.61 (dd, 1 H, *J* = 9.1, 2.1 Hz, 4-H), 7.96 (d, 1 H, *J* = 2.1 Hz, 6-H), 8.86 (d, 1 H, *J* = 9.1 Hz, 3-H), 11.0 (s, 1 H). – ¹⁴N NMR (CDCl₃): δ = –285 ($\Delta\nu_{1/2}$ = 600 Hz, NH), –14 ($\Delta\nu_{1/2}$ = 160 Hz, NO₂). – ¹⁵N NMR, INEPT (CDCl₃): δ = –282.6 (*J* = 91.1 Hz, NH). – MS (70 eV); *m/z*: 223 [*M*⁺]. – C₁₀H₁₃N₃O₃ (223.2): calcd. C 53.81, H 5.87, N 18.82; found C 53.56, H 6.29, N 18.74.

Reaction of 2,4-Dibromonitrosobenzene (1d) with *tert*-Butylamine: Excess *t*BuNH₂ was added to a solution of **1d** (0.5 g, 1.8 mmol) in CH₃CN (4 mL). The mixture was heated under reflux until the

reaction was complete (see Table 1). The solvent was then completely evaporated in vacuo and the residue was chromatographed (silica gel, eluent benzene) to yield **2d** (184 mg) and **4d** (175 mg).

3,5-Dibromo-*N*-tert-butyl-2-nitrosoaniline (2d): Brown crystals, m.p. 123–125°C. – UV (CH₃OH): $\lambda_{\max}$ (lg ϵ) = 216 nm (4.31), 237 (4.32), 330 (4.11), 460 (3.84). – ¹H NMR (CDCl₃): δ = 1.47 (s, 9 H, tBu), 7.22 (d, 1 H, J = 1.7 Hz, 6-H), 7.31 (d, 1 H, J = 1.7 Hz, 4-H), 12.23 (s, 1 H, NH). – ¹⁵N NMR, INEPT (CDCl₃): δ = –281.8 (J = 90.0 Hz, NH). – MS (70 eV); m/z : 338, 336, 334 (1:2:1) [M⁺]. – C₁₀H₁₂N₂OBr₂ (336.0): calcd. C 35.74, H 3.60, N 8.34, Br 47.56; found C 35.64, H 3.89, N 8.30, Br 47.72.

Bis(2,4-dibromophenyl)diazene *N*-Oxide (4d): Colorless crystals, m.p. 149–150°C (benzene). – ¹H NMR ([D₆]DMSO): δ = 7.79 (dd, 1 H, J = 8.7, 2.1 Hz), 7.89 (AB system, 2 H), 7.93 (d, 1 H, J = 8.7 Hz), 8.11 (d, 1 H, J = 2.1 Hz), 8.21 (d, 1 H, J = 1.7 Hz). – ¹³C NMR ([D₆]DMSO): δ = 115.3, 119.6, 122.0, 124.30, 124.6, 126.6, 131.2, 132.0, 135.3, 135.9, 140.7, 147.5. – ¹⁴N NMR ([D₆]DMSO): δ = –51 [J = 270 Hz, N(O)=]. – MS (70 eV); m/z : 518, 516, 514, 512, 510 (1:4:6:4:1) [M⁺]. – C₁₂H₆Br₄N₂O (513.8): calcd. C 28.05, H 1.18, Br 62.21, N 5.45; found C 28.16, H 1.22, Br 62.45, N 5.47.

2d from 7: *tert*-Butylamine (7.5 mL, 65 mmol) was added to a stirred solution of 2,4,6-tribromonitrosobenzene **7** (1.72 g, 5 mmol) in CH₃CN (65 mL). After 16 h at room temperature, the reaction mixture was heated for an additional 10 min at 70°C. After cooling, the solvent was removed in vacuo, the residue was washed with 15% aqueous hydrochloric acid, and chromatographed (silica gel, eluent benzene) to yield 1.45 g (85%) of **2d**, identical to the sample obtained above.

Reaction of *para*-Nitronitrosobenzene (1c) with 1-Adamantylamine in DMSO: 1-Adamantylamine (210 mg, 1.4 mmol) was added to a stirred solution of **1c** (90 mg, 0.6 mmol) in DMSO (30 mL). After the reaction was complete (see Table 2), the DMSO solution was poured into water (200 mL) and the resulting mixture was extracted with diethyl ether. The combined ethereal extracts were dried (MgSO₄) and the solvent was removed in vacuo. The residue was chromatographed (silica gel, eluent benzene) to yield **2e** (52 mg) and **4c** (46 mg).

***N*-(1-Adamantyl)-5-nitro-2-nitrosoaniline (2e):** Bright-red crystals, m.p. 173–175°C (decomp.). – IR (KBr): $\tilde{\nu}$ = 1350 cm^{–1}, 1550 (NO₂). – ¹H NMR (CDCl₃): δ = 1.79 (s, 6 H), 2.11 (s, 6 H), 2.23 (s, 3 H), 7.58 (dd, 1 H, J = 9.4, 2.0 Hz, 4-H), 8.06 (d, 1 H, J = 2.0 Hz, 6-H), 8.82 (d, 1 H, J = 9.4 Hz, 3-H), 10.90 (s, 1 H, NH). – ¹⁴N NMR (CDCl₃): δ = –14 ($\Delta\nu_{1/2}$ = 220 Hz, NO₂). – MS (70 eV); m/z : 301 [M⁺]. – C₁₆H₁₉N₃O₃ (301.3): calcd. C 63.77, H 6.36, N 13.94; found C 63.56, H 6.67, N 13.87.

Reaction of 1c in the Presence of MnO₂: This reaction of **1c** with 1-adamantylamine was carried out as described above, but in the presence of MnO₂ (100 mg, 1.2 mmol, prepared from KMnO₄ and MnSO₄ in H₂SO₄ and dried at 120°C,^[19] see Table 2).

Reaction of 1c in the Presence of MnO₂ and Pyridine: This reaction of **1c** with 1-adamantylamine was carried out as described above, but in the presence of pyridine (0.45 mL, 4.65 mmol, see Table 2).

Reaction of 1a–c and 2c with *tert*-Butylamine in the Presence of an Oxidant

General Procedure: *tert*-Butylamine (0.2 mL, 9.75 mmol) and the oxidizing agent (5 mmol) were added to a stirred solution of the nitroso compound (3.25 mmol) in CH₃CN (2 mL). After the reaction was complete (see Table 1), the inorganic by-products were

filtered off, the filtrate was concentrated in vacuo, and the residue was chromatographed on silica gel (see Table 1).

***N*-tert-Butyl-4-nitroaniline (5):** A 0.5 M solution of *m*CPBA in CH₂Cl₂ (1 mL) was added dropwise to a stirred solution of **3a** (89 mg, 0.5 mmol) in CH₂Cl₂ (2 mL). After 2 min, the reaction mixture was carefully shaken with concentrated Na₂CO₃ solution until the evolution of CO₂ subsided. The organic layer was then separated and dried (MgSO₄). The solvent was evaporated to leave **5** as a yellow solid (93 mg, 95%), m.p. 70–72°C (hexane, ref.^[21] m.p. 71.1–71.6°C). – ¹H NMR (CDCl₃): δ = 1.42 (s, 9 H), 6.62 (d, 2 H), 8.02 (d, 2 H).

***N,N'*-Di-*tert*-butyl-4-nitro-2-nitroso-1,3-phenylenediamine (8a):** The reaction of **2c** with *t*BuNH₂ in CH₃CN was carried out as described for the reaction of **1b**. After the reaction was complete (see Table 1), the solvent was removed in vacuo, and the residue was passed through a short column of silica gel, eluting with benzene. Diamine **8a** was obtained as deep-blue crystals, m.p. 141–144°C (hexane). – IR (KBr): $\tilde{\nu}$ = 1320 cm^{–1}, 1540 (NO₂). – UV (CH₃OH): $\lambda_{\max}$ (lg ϵ) = 214 nm (4.59), 244 (4.52), 275 (3.79), 410 (3.81), 600 (3.86). – UV (pentane): $\lambda_{\max}$ = 276 nm, 400, 560. – ¹H NMR (CDCl₃): δ = 1.46 [s, 9 H, *t*Bu (C-1)], 1.52 [s, 9 H, *t*Bu (C-3)], 6.75 (s, 2 H, Ar), 7.77 [s, 1 H, NH (C-3)], 12.79 [s, NH (C-1)]. – ¹⁴N NMR (CDCl₃): δ = –285 ($\Delta\nu_{1/2}$ = 950 Hz, NH), –12 ($\Delta\nu_{1/2}$ = 200 Hz, NO₂). – MS (70 eV); m/z : 294 [M⁺]. – C₁₄H₂₂N₄O₃ (294.6): calcd. C 57.13, H 7.53, N 19.03; found C 57.32, H 7.22, N 19.10.

***N,N'*-Bis(1-adamantyl)-4-nitro-2-nitroso-1,3-phenylenediamine (8b):** 1-Adamantylamine (60 mg, 0.4 mmol) and pyridine (0.2 mL, 2.68 mmol) were added to a stirred solution of **1c** (20 mg, 0.134 mmol) in DMSO (7 mL) in the presence of MnO₂ (40 mg, 0.268 mmol). After the reaction was complete (see Table 2), the DMSO solution was poured into water (50 mL) and the resulting mixture was extracted with diethyl ether. The combined ethereal extracts were dried (MgSO₄) and the solvent was removed in vacuo. The residue was chromatographed (silica gel, eluent benzene) to yield **8b** (35 mg, 59%) as deep-blue crystals, m.p. 215–217°C (decomp.). – IR (KBr): $\tilde{\nu}$ = 1330 cm^{–1}, 1540 (NO₂). – ¹H NMR (CDCl₃): δ = 1.75 (s, 6 H), 1.77 (s, 6 H), 2.09 (s, 6 H), 2.15 (s, 6 H), 2.20 (br. s, 6 H), 6.82 (s, 2 H), 7.67 (s, 1 H, NH), 12.75 (s, 1 H, NH). – ¹⁴N NMR (CDCl₃): δ = –17.30 ($\Delta\nu_{1/2}$ = 200 Hz). – MS (70 eV); m/z : 450 [M⁺]. – C₂₆H₃₄N₄O₃ (450.3): calcd. C 69.31, H 7.61, N 12.43; found C 69.46, H 7.51, N 12.36.

8b from 2e: 1-Adamantylamine (100 mg, 0.5 mmol) and MnO₂ (30 mg, 0.34 mmol) were added to a stirred solution of **2e** (50 mg, 0.17 mmol) in DMSO (17 mL). After the reaction was complete (see Table 2), work-up was carried out as described above to give **8b** (29 mg).

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