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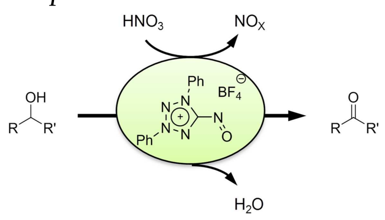

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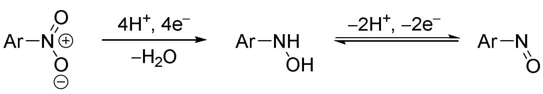
ABSTRACT

We describe the synthesis of a mesoion-derived nitroso compound, 5-nitroso-1,3-diphenyltetrazolium tetrafluoroborate (**1**), and its application in the oxidation of alcohols. The structure of **1** was fully characterized by X-ray analysis, showing that it exists as a monomer in the solid state. In the cyclic voltammetric analysis of **1**, a reversible redox peak was observed at 0.43 V (vs. Ag/Ag^+ in MeCN) under acidic conditions. It was subsequently shown that the nitrosotetrazolium salt **1** is capable of stoichiometrically oxidizing alcohols to the corresponding carbonyl compounds effectively. This nitroso heterocycle and its reduced form, i.e., the corresponding mesoionic hydroxyamide, participate in a redox cycle involving the catalytic oxidation of alcohols by the aid of HNO_3 under mild conditions.

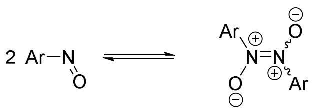
1. Introduction

The oxidative conversion of alcohols into the corresponding aldehydes and ketones is an essential process in organic chemistry.[1a,b] With the aim of developing environmentally friendly processes, organocatalyst-mediated oxidation reactions have been extensively explored, and nitroxyl radicals have played a major role in catalytic oxidations without heavy metals.[1c–h] Nitroxyl radicals are oxidized in situ to *N*-oxoammonium salts, which serve as the actual oxidizing agents for alcohols. During our study of the oxidation of alcohols with nitroxyl radicals,[2] we became interested in nitroso compounds, which are structurally similar to *N*-oxoammonium salts. Aromatic nitroso compounds are generally prepared by reduction of nitro compounds to hydroxylamines followed by oxidation (eq. 1), indicating that nitroso and hydroxylamino derivatives would have the potential to catalyze alcohol oxidation reactions similarly to nitroxyl radicals.[3]



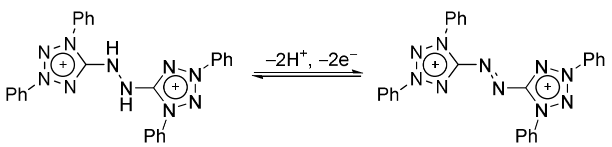
(1)

The redox function of nitroso compounds has been observed in reactions of reduced nicotinamides,[4] dihydroflavins,[4c,5] dihydropyridines,[6] ascorbates,[7] thiols,[8] and selenols.[9] To the best of our knowledge, however, only one example has been reported for the oxidation of alcohols.[3c] *C*-nitroso compounds generally exist in equilibrium between monomeric and more stable dimeric species (eq. 2),[10] which presumably suppresses the reactivity of the nitroso functionality.



(2)

From a physicochemical point of view, mesoionic compounds have attracted attention as activators of the nitroso group, because of their unique electronic and electrochemical properties.[11a] We systematically investigated 1,3-diphenyltetrazolium mesoionic compounds[11b–11d] and found that their dimeric species undergo reversible redox cycles involving remarkably stable radical intermediates (eq. 3).[11b]

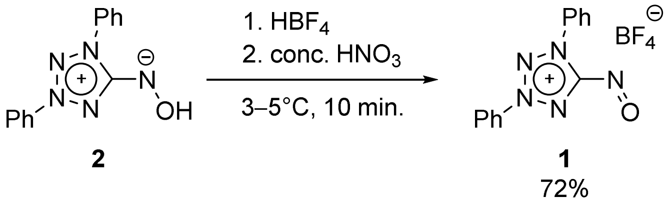


(3)

The positively charged tetrazolium rings are expected to prevent dimerization of the nitroso groups by electrostatic repulsions and enhance the electrophilicity of the nitroso moiety, resulting in the promotion of catalytic activity.[2f] Thus, we envisaged the introduction of a nitroso group into a mesoionic tetrazolium ring,[12] and disclose herein the synthesis of 5-nitroso-1,3-diphenyltetrazolium tetrafluoroborate (**1**) and its evaluation as a mediator for alcohol oxidation.

2. Results and Discussion

Compound **1** was readily synthesized by oxidation of 1,3-diphenyltetrazolium-5-hydroxyamide (**2**): exposure of hydroxyamide **2** to concentrated HNO_3 at 3–5 °C gave **1** as pale green crystals in 72% yield (Scheme 1). Compound **1** is stable in MeCN, TFA, and $MeNO_2$, but gradually decomposes in acetone, and THF. A solution of **1** in MeCN exhibits a greenish color, which is characteristic of monomeric nitroso compounds.[3a]



Scheme 1. Synthesis of 5-nitroso-1,3-diphenyltetrazolium salt **1**.

The structure of **1** was confirmed by X-ray diffraction (Figure 1), showing no interaction between the nitroso groups in **1** and a N=O bond length (1.21 Å) similar to that of typical nitroso monomers (around 1.2 Å).[10c]

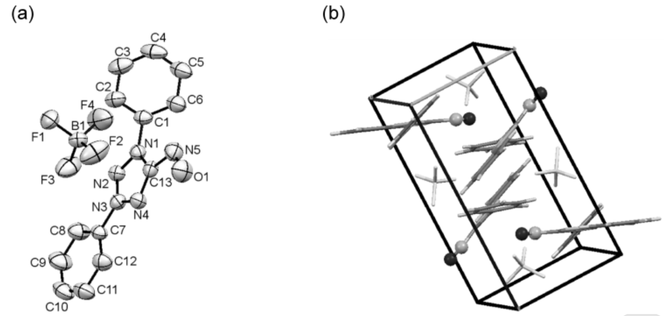
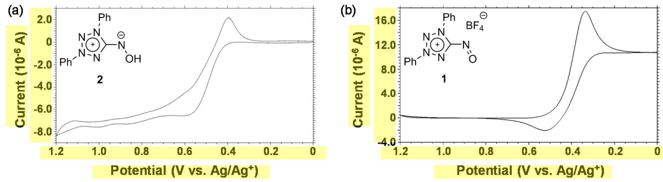


Figure 1 X-ray structure of **1** (CCDC 1441100). (a) ORTEP with probability ellipsoids drawn at the 50% level. (b) Packing structure. Black and gray balls represent O and N atoms of the nitroso group, respectively. Selected bond distances (Å) and angles (deg): C(13)-N(5) = 1.470(5), N(5)-O(1) = 1.211(5), N(1)-C(13)-N(5) = 120.8(3), N(4)-C(13)-N(5) = 128.1(3), C(13)-N(5)-O(1) = 110.7(3).

These observations prompted us to evaluate the redox behavior of **1** and **2**. Cyclic voltammograms of both compounds were obtained in MeCN containing 100 mM tetra-*n*-butylammonium perchlorate (Bu_4NClO_4) as a supporting electrolyte, at room temperature under N_2 atmosphere. When the scan of **2** was initiated in the positive direction, one peak was detected at 0.10 V (vs. Ag/Ag^+), whereas no peak was observed in the return scan in the negative direction. Compound **1** exhibited only a reduction wave at 0.12 V during the initial cathodic sweep, whereas no oxidation wave was observed in the return sweep to positive potential. These peaks are attributed to the nitroso moiety,[3d] and their irreversibility can be associated with the lack of a proton for the reduction of **1** to **2** and the instability of **1** toward **2** under neutral conditions. In fact, exposure of **1** to a solution of **2** in MeCN resulted in a prompt disappearance of both **1** and **2**. Thus, the voltammetric measurements of **1** and **2** were performed under acidic conditions. In the presence of trifluoroacetic acid (TFA) as a proton source, the voltammograms of **2** and **1** exhibited reversible waves at $E_{1/2}$ = 0.48 V and 0.43 V, respectively (Figure 2). These waves, associated with the redox couple **1**-**2**, are ~0.3 V higher than the irreversible waves observed in the absence of a proton donor. A similar shift of redox peaks dependent on the proton source was reported for nitrosobenzene derivatives.[3d,3e]

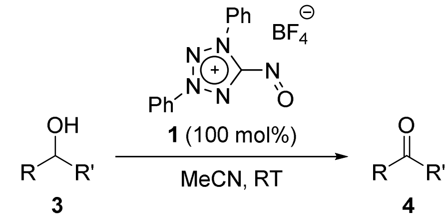
Figure 2 Cyclic voltammograms of (a) **2** and (b) **1** in MeCN



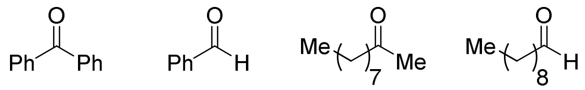
solution containing 100 mM Bu_4NClO_4 and 26 mM TFA, at room temperature under N_2 atmosphere. Scan rate = 10 mV/s, working electrode: glassy carbon, reference electrode: Ag/Ag^+, concentration of samples = 1.0 mM.

In order to evaluate the oxidation ability of **1**, the reaction of a series of alcohols (**3a**–**d**) with a stoichiometric amount of **1** was examined (Scheme 2). When **1** was mixed with benzhydrol (**3a**) in MeCN at room temperature, benzophenone (**4a**) was rapidly obtained in high yield (97%, 0.5 h), and **2** was obtained in moderate yield (57%). Other primary, secondary, benzylic, and aliphatic alcohols (**3b**–**d**) were also converted into the corresponding aldehydes or ketones (**4b**–**d**) in moderate-to-quantitative yields under the same conditions. These results clearly showed that, in contrast to typical nitroso compounds,[3] **1** has the practical ability to oxidize alcohols, which is almost comparable to that of conventional 2,2,6,6,-tetramethylpiperidine-1-oxoammonium cation ($TEMPO^+$), a structurally related nitroso compound.[13]

Scheme 2. Stoichiometric oxidation of alcohols with **1**[a]



product, yield[b] (time)

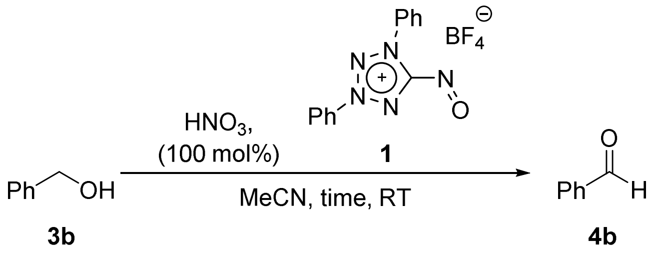


4a, 97%[c] (0.5 h)	**4b**, 94% (0.5 h)	**4c**, 94% (0.5 h)	**4d**, 65% (1.0 h)

[a]Conditions: equimolar amounts of alcohol (0.050 mmol) and **1** (0.050 mmol) in MeCN (2.0 mL) were used at room temperature. [b]Yield determined by GC using *n*-cetane as the internal standard. [c]Yield determined by ^1H NMR using 1,3,5-trimethoxybenzene as the internal standard after workup.

The results of the stoichiometric oxidation and electrochemical investigation suggest that a catalytic version of the present oxidation would be realized in the presence of an appropriate re-oxidant that can convert **2** back to **1** in situ. As a natural extension, HNO_3 was initially examined. When the reaction of benzyl alcohol (**3b**) was performed with a catalytic amount of **1** (5 mol%) and an equimolar amount of HNO_3, **4b** was obtained almost quantitatively (entry 1, Scheme 3). Decreasing the catalyst loading to 1 mol% caused a significant reduction in the reaction rate (entry 2). In the absence of **1**, the oxidation did not proceed at all. Thus, we found that 5 mol% of **1** was the optimum catalyst concentration for the catalytic oxidation.

Scheme 3. Catalytic oxidation of **3b** with **1**[a]

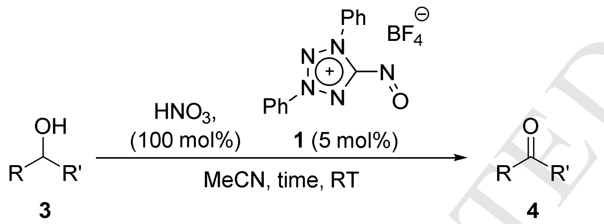


entry	catalyst **1** [mol%]	time [h]	yield [%][b]
1	5	1.3	93
2	1	31	89

[a]Conditions: equimolar amounts of alcohol (0.20 mmol) and HNO_3 (0.21 mmol) in MeCN (2.0 mL) were used at room temperature. [b]Yield determined by GC using *n*-cetane as the internal standard.

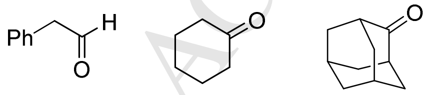
We then examined the scope of alcohols for the catalytic oxidation (Scheme 4). The reactions of benzylic, aliphatic, and cycloaliphatic alcohols (**3a**–**3d**, **3f**, and **3g**) proceeded in moderate to quantitative yields. However, phenethyl alcohol (**3e**) gave a relatively low yield of **4e**. It is noted that **1** exhibited a preference for the reaction of aliphatic secondary alcohol **3c** over primary alcohol **3d**, a trend consistent with 2,2,6,6-tetramethylpiperidine-1-oxyl (TEMPO)-catalyzed oxidations.[14] This method was able to be applicable for 1.0 mmol-scale oxidations of **3a** (98%, 1.0 h) and **3g** (96%, 1.5 h).

Scheme 4. Catalytic oxidation of various alcohols.



product, yield (recovery of **3**)[b] (time)

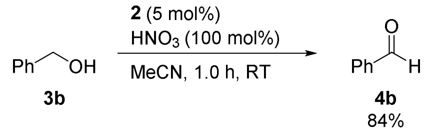
4a, 96% (0%)[c] (1.0 h) **4b**, 93% (2%) (1.3 h) **4c**, 75% (12%) (3.0 h) **4d**, 40% (26%) (4.0 h)

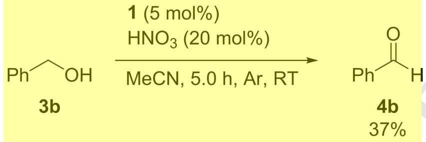


4e, 16% (63%) (5.0 h) **4f**, 41% (28%) (1.0 h) **4g**, 100%[d] (2.0 h)

[a]Conditions: equimolar amounts of alcohol (0.20 mmol), HNO_3 (0.21 mmol), and 5 mol% of **1** (0.010 mmol) in MeCN (2.0 mL) were used at room temperature. [b]Yield determined by GC using *n*-cetane as the internal standard. [c]Isolated yield. [d]Yield determined by ^1H NMR using *n*-cetane as the internal standard.

In order to investigate the re-oxidation process, the stoichiometric reaction of **3b** with hydroxyamide **2** (5 mol%) instead of **1** and HNO_3 (100 mol%) in MeCN was performed to give **4b** in high yield (eq. 4). In addition, with a restricted amount of nitric acid (20 mol%) under an argon atmosphere (eq. 5), **3b** was converted to **4b** in 37% yield which is close to theoretical value (35%).

 (4)

 (5)

We also confirmed that protonated **2**, prepared in situ with HBF_4, has no oxidation activity in the stoichiometric reaction of **3b**. On the basis of these results, we propose a plausible mechanism as described in Figure 3. In the first step, **1** oxidizes an alcohol to give the corresponding aldehyde or ketone and is converted to protonated **2**, which undergoes oxidation to **1** by HNO_3, thus closing the catalytic cycle.

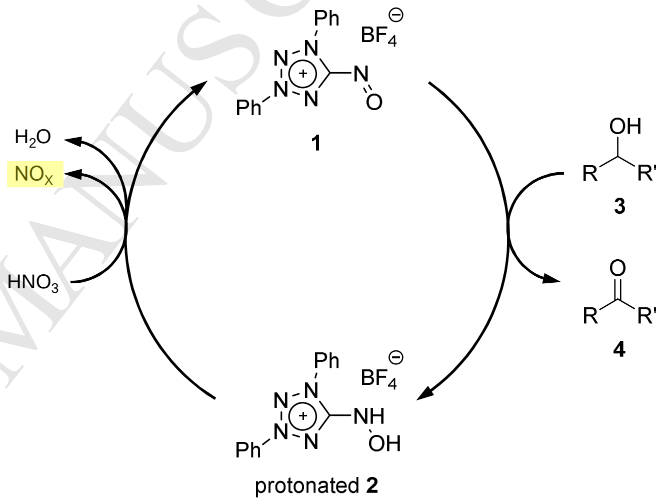
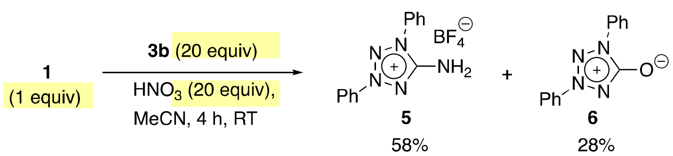


Figure 3. Plausible mechanism of the **1**-catalyzed oxidation.

The incomplete oxidation of **3c**–**3f** indicates that **1** is partially degraded during the catalytic reaction. In order to gain further insight into this matter, the reaction of **3b** with a catalytic amount of **1** was performed in a larger scale and the mixture was analyzed after a longer reaction time. After 4 h, tetrazolium amine **5** and olate **6** were isolated, both of which showed no catalytic activity (Scheme 5). Olate **6** is considered to come from the hydrolysis of **1** during workup.[15] Although the precise mechanism for the formation of **5** is still unclear at this stage, the reduction of a nitroso group to an amino group has been documented.[3c]

Scheme 5. Decomposition of **1** in the catalytic oxidation.



3. Conclusion

Nitroso derivative organocatalyst **1** was synthesized by simple oxidation of tetrazolium-5-hydroxyamide **2** with concentrated HNO_3. The mesoionic nitroso compound **1** strongly prefers the monomeric form even in the solid state. In the presence of concentrated HNO_3 as an acidic re-oxidant, **1** is capable of catalytically oxidizing primary, secondary, benzylic, and aliphatic alcohols to the corresponding aldehydes and ketones in moderate to quantitative yields. Our results will expand the application of nitroso compounds and demonstrate the utility of a new organocatalyst.

4. Experimental Section

4.1. General

Melting point was measured by a Yanaco MP 50533 and uncorrected. ^{1}H and ^{13}C NMR spectra were recorded on a Varian Mercury spectrometer (300 MHz) and a Bruker AVANCE 400 Plus NanoBay spectrometer (^{1}H NMR: 400 MHz, ^{13}C NMR: 100 MHz). IR spectra were obtained on a Jasco FT/IR-200. High resolution ESI-TOF mass spectroscopy was carried out on a Waters, Synapt G2 HDMS. Elemental analyses were done with a Elementar vario EL cube. Electrochemical experiments were carried out on a BAS ALS/chi 620A electrochemical analyzer. For cyclic voltammetry, a 3 mm glassy carbon electrode was used as working electrode. The counter electrode consisted of a Pt wire and Ag/Ag^+ (0.01 M in MeCN / 0.1 M Bu_4NClO_4) was used as reference electrode. To remove O_2 from the solution, N_2 gas was bubbled for 10 min prior to each electrochemical analysis. Gas chromatography was carried out on a Shimadzu GC-2014 equipped with a flame-ionization detector and a capillary column (Agilent DB-WAX, 30 m). X-ray diffraction data were collected on a Rigaku VariMax RAPID II, Mo-Kα radiation.

1,3-Diphenyltetrazolium-5-hydroxyamide (**2**) was synthesized according to the literature.[11c] Alcohols were purified by distillation just before use. MeCN was dried by distillation from CaH_2 powder. Other commercially available materials were used as received. All the reactions were performed under air and monitored by GC or ^{1}H NMR.

4.2 Synthesis of mesoionic nitroso compound 1

*Synthesis of 5-nitroso-1,3-diphenyltetrazolium tetrafluoroborate (**1**).*

1,3-Diphenyltetrazolium-5-hydroxyamide (**2**, 51.1 mg, 0.200 mmol) was suspended in CH_2Cl_2 (0.50 mL). HBF_4 (6.3 M, 1.86 mL, 11.6 mmol) was added to the mixture and stirred vigorously and then CH_2Cl_2 was evaporated under reduced pressure (100 mmHg). The resulting suspension was cooled at 3–5 °C and concentrated HNO_3 (0.620 mL, 8.14 mmol) was added. The mixture was stirred vigorously for 10 min while keeping the temperature constant. The pale green precipitate was filtered through a glass filter (G4), washed with H_2O, THF:CH_2Cl_2 = 8:2, and CH_2Cl_2. The solid was dissolved in MeCN and filtered through a glass filter (G4). The filtrate was evaporated under reduced pressure at room temperature to give green crystals of **1** (0.487 mg, 0.143 mmol, 72%). Crystals suitable for X-ray analysis were obtained by recrystallization from MeCN/CCl_4. Melting point: 110.2–111.2 °C (from MeCN); [Found: C, 46.01; H, 3.04; N, 20.71. $C_{13}H_{10}BF_4N_5O$ requires C, 46.05; H, 2.97; N, 20.66%]; δ_H (400 MHz, MeCN-d_3) 7.86 (t, 2H, J = 7.8 Hz, *m* of Ph), 7.93–7.99 (m, 3H, *p* and *m* of Ph), 8.05 (t, 1H, J = 7.4 Hz, *p* of Ph), 8.31 ppm (d, 4H, *o* of Ph); δ_C (100 MHz, acetone-d_6) 122.2 (*m* of Ph), 126.5 (*m* of Ph), 130.8 (*o* of Ph), 131.0 (*o* of Ph), 131.7 (*i* of Ph), 134.2 (*p* of Ph), 134.7 (*p* of Ph), 134.9 (*i* of Ph), 160.0 ppm (C^+); IR (KBr, cm^{-1}) 3109, 3076, 2921, 2852, 1701, 1618, 1562, 1490, 1333, 1291, 1176, 1123, 1084, 1063, 1041, 999, 767, 680, 419; HRMS (ESI$^+$-TOF): **1**–BF_4^-+2H, found 254.1047. $C_{13}H_{11}N_5O$ requires 254.1042.

4.3. General procedure for the stoichiometric oxidation.

The following oxidation of benzyl alcohol represents the general procedure. A mixture of nitrosotetrazolium salt (**1**, 17 mg, 0.049 mmol) and benzyl alcohol (**3b**, 5.2 µL, 0.050 mmol) was stirred in MeCN (2.0 mL) at room temperature for 0.5 h, in the presence of *n*-cetane (t_R = 5.4 min.) as an internal standard. At intervals, aliquots were analyzed by GC after passing through a SiO_2 column (eluting with CH_2Cl_2). The yield of **4b** (t_R = 4.5 min.) was calculated to be 94% based on a calibration curve using an authentic sample. In the case of benzhydrol, the yield of **4a** and **2** were calculated by ^{1}H NMR to be 97% and 57% based on the peaks of 7.80 ppm (4H of **4a**) and 8.19 ppm (2H of **2**) using 1,3,5-trimethoxybenzene (6.08 ppm, 3H) as a standard.

Retention times for the carbonyls **4b–d**: t_R = 4.5 min. for **4b** in 94% yield; t_R = 3.9 min. for **4c** in 94% yield; t_R = 4.0 min. for **4d** in 65% yield.

4.4. General procedure for the catalytic oxidation.

The following oxidation of benzyl alcohol represents the general procedure. A mixture of nitrosotetrazolium salt (**1**, 3.6 mg, 0.011 mmol), concentrated HNO_3 (16 µL, 0.21 mmol), and benzyl alcohol (**3b**, 22 mg, 0.20 mmol) was stirred in MeCN (2.0 mL) at room temperature for 1.3 h in the presence of *n*-cetane (t_R = 5.4 min.) as an internal standard. At intervals, aliquots were analyzed by GC after passing through a SiO_2 column (eluting with CH_2Cl_2). The yield of **4b** (t_R = 4.5 min.) was calculated to be 93% based on a calibration curve using an authentic sample. In the case of 2-adamantanol (**4g**), the yield was calculated by ^{1}H NMR based on the peaks of 2.63 ppm (2H of **4g**) using *n*-cetane (0.88 ppm, 6H) as a standard.

Retention times for the carbonyls **4b–4f**: t_R = 4.5 min. for **4b** in 93% yield; t_R = 3.9 min. for **4c** in 75% yield; t_R = 4.0 min. for **4d** in 40% yield; t_R = 6.9 min. for **4e** in 16% yield; t_R = 2.3 min. for **4f** in 41% yield.

4.5 General procedure for the catalytic oxidation on a 1.0 mmol scale.

A mixture of nitrosotetrazolium salt (**1**, 17.0 mg, 0.0500 mmol), concentrated HNO_3 (76.1 µL, 1.00 mmol), and alcohols **3a** or **3g** (1.00 mmol) was stirred in MeCN (10.0 mL) at room temperature for 1.0–1.5 h. The solvent was evaporated under reduced pressure and the residue was passed through a SiO_2 column (eluting with CH_2Cl_2) to give the corresponding ketones **4a** or **4g**.

*Benzophenone **4a**.* Colorless liquid (180 mg, 0.986 mmol, 98%). δ_H (300 MHz, $CDCl_3$) 7.49 (t, 4H, J = 7.3 Hz, *m* of Ph), 7.60 (t, 2H, J = 7.4 Hz, *p* of Ph), 7.81 ppm (d, 4H, J = 7.2 Hz, *o* of Ph).

*2-Adamantanone **4g**.* Colorless crystals (145 mg, 0.968 mmol, 96%). δ_H (300 MHz, $CDCl_3$) 1.94–2.11 (m, 12H), 2.55 ppm (s, 2H).

4.6. Decomposition of 1 in the catalytic oxidation (Scheme 5).

A mixture of nitrosotetrazolium salt (**1**, 68 mg, 0.20 mmol), concentrated HNO_3 (0.42 g, 4.0 mmol), and benzyl alcohol (**3b**, 0.43 g, 4.0 mmol) was stirred in MeCN (40 mL) at room temperature. The reaction was monitored by TLC until **3b** disappeared completely (4 h). The solvent was evaporated under reduced pressure and Et_2O (c.a. 1 mL) was added. The formed precipitate was filtered and washed with Et_2O to give colorless crystal of **5** (37 mg, 58%) and a yellow filtrate. The yield of **6**, found in the filtrate, was estimated by ^{1}H NMR to be 28% based on the peaks of 8.12–8.14 ppm (4H of **6**) and 6.08 ppm (3H of 1,3,5-trimethoxybenzene as a standard).

5. References and Notes

1. (a) Fernandez, M. I.; Tojo, G. *Oxidation of Alcohols to Aldehydes And Ketones: A Guide to Current Common Practice*, Springer, New York, **2006**. (b) Bäckvall, J. E.; *Modern Oxidation Methods*, 2nd ed. Wiley-VCH, Weinheim, **2010**. (c) Ishii, Y.; Sakaguchi, S.; Iwahama, T. *Adv. Synth. Catal*. **2001**, *343*, 395. (d) Sheldon, R. A.; Arends, I. W. C. E. *Adv. Synth. Catal.* **2004**, *346*, 1051. (e) Bobbitt, J. M.; Brückner, C.; Merbouh, N. *Organic Reactions* **2010**, *74*, 103. (f) Iwabuchi, Y. *Chem. Pharm. Bull*. **2013**, *61*, 1197. (g) Wertz, S.; Studer, A. *Green Chem.* **2013**, *15*, 3116. (h) Ryland, B. L.; Stahl, S. S.; *Angew. Chem. Int. Ed.* **2014**, *126*, 8968.
2. Hirashita, T.; Nakanishi, M.; Uchida, T.; Yamamoto, M.; Araki, S.; Arends, I. W. C. E.; Sheldon, R. A. *ChemCatChem* **2016**, *8*, 2704–2709.
3. For reviews on the reactions of nitroso compounds, see: (a) Zuman, P.; Shah, B. *Chem. Rev*. **1994**, *94*, 1621–1641. (b) Maji, B.; Yamamoto, H. *Bull. Chem. Soc. Jpn*. **2015**, *88*, 753–762. For the oxidation of alcohols with *p*-nitrosodimethylaniline: (c) Noller, C. R. *Chemistry of Organic Compounds*, 3rd ed. Saunders, W. B. Philadelphia, **1965**, p. 585. For the electrochemistry of nitrosoarenes, see: (d) Chuang, L.; Fried, I.; Elving, P. J. *Anal. Chem*. **1964**, *36*, 2426–2431. (e) Mikhal'chenko, L. V.; Syroeshkin, M. A.; Leonova, M. Y.; Mendkovich, A. S.; Rusakov, A. I.; Gul'tyai, V. P. *Russ. J. Electrochem*. **2011**, *47*, 1205–1210.
4. (a) Kim, D.; Kadlubar, F. F.; Teitel, C. H.; Guengerich, F. P. *Chem. Res. Toxicol*. **2004**, *17*, 529–536. (b) van Ophem, P. W.; van Beeumen, J.; Duine, J. A. *Eur. J. Biochem*. **1993**, *212*, 819–826. (c) Leskovac, V.; Svircevic, J.; Trivic, S.; Popovic, M.; Radulovic, M. *Int. J. Biochem*. **1989**, *21*, 825–834. (d) Kovar, J.; Plocek, J. *Biochem. J*. **1986**, *235*, 537–543. (e) Awano, H.; Hirabayashi, T.; Takagi, W. *Tatrahedron Lett*. **1984**, *25*, 2005–2008. (f) Kovar, J.; Simek, K.; Kucera, I.; Matyska, L. *Eur. J. Biochem*. **1984**, *139*, 585–591. (g) Becker, A. R.; Sternson, L. A. *Bioorg. Chem*. **1980**, *9*, 305–312. (h) Koerber, S. C.; Schack, P.; Au, A. M. J.; Dunn, M. F.; *Biochem*. **1980**, *19*, 731–738. (i) Dunn, M. F.; Bernhard, S. A. *Biochem*. **1971**, *10*, 4569–4575.
5. Gibian, M. J.; Baumstark, A. L.; *J. Org. Chem*. **1971**, *36*, 1389–1391.
6. Mao, Y. Z.; Jin, M. Z.; Liu, Z. L.; Wu, L. M. *Org. Lett*. **2000**, *2*, 741–742.
7. Vuina, D.; Pilepic, V.; Ljubas, D.; Sankovic, K.; Sajenko, I.; Ursic, S. *Tetrahedron Lett*. **2007**, *48*, 3633–3637.
8. (a) Bond, D. C. US2494687, **1950**. (b) Gulbaran, E. *Suomen Kemistilehti*, **1964**, *37*, 229. (c) Eyer, P.; Schneller, M. *Biochem. Pharmacol*. **1983**, *32*, 1029–1036.
9. (a) Fujimori, K.; Yoshimoto, H.; Oae, S. *Tetrahedron Lett*. **1979**, *45*, 4397–4398. (b) Nuttall, K. L.; Allen, F. S.; *Inorg. Chim. Acta* **1984**, *92*, 33–36.
10. (a) Dietrich, H.; Hodgkin, D. C.; *J. Chem. Soc*. **1961**, 3686–3690. (b) Tanimura, M.; Kobori, K.; Kashiwagi, M.; Kinoshita, Y. *Bull. Chem. Soc. Jpn*. **1970**, *43*, 1962–1966. (c) Webster, M. S. *J. Chem. Soc*. **1956**, 2841–2845.
11. For reviews on mesoionic compounds, see: (a) Ollis, W. D.; Stanforth, S. P.; Ramsden, C. A. *Tetrahedron* **1985**, *41*, 2239–2329. For the diphenyltetrazolium mesoions, see: (b) Araki, S.; Yamamoto, K.; Inoue, T.; Fujimoto, K.; Yamamura, H.; Kawai, M.; Butsugan, Y.; Zhou, J.; Eichhorn, E.; Rieker, A.; Huber, M. *J. Chem. Soc*. *Perkin Trans 2* **1999**, 985–995. (c) Araki, S.; Yamamoto, K.; Yagi, M.; Inoue, T.; Fukagawa, H.; Hattori, H.; Yamamura, H.; Kawai, M.; Butsugan, Y. *Eur. J. Org. Chem.* **1998**, 121–127. (d) Araki, S.; Wanibe, Y.; Uno, F.; Morikawa, A.; Yamamoto, K.; Chiba, K.; Butsugan, Y. *Chem. Ber.* **1993**, *126*, 1149–1155.
12. The synthesis of *N*-nitrosotetrazolium derivatives failed: Christophersen, C.; Treppendahl, S. *Acta Chem. Scand*. **1972**, *26*, 858–860.
13. Miyazawa, T.; Endo, T.; Shiihashi, S.; Okawara, M. *J. Org. Chem*. **1985**, *50*, 1332–1334.
14. (a) Rahimi, A.; Azarpira, A.; Kim, H.; Ralph, J.; Stahl, S. S. *J. Am. Chem. Soc*. **2013**, *135*, 6415–6418. (b) Aellig, C.; Scholz, D.; Conrad, S.; Hermans, I. *Green Chem*. **2013**, *15*, 1975–1980.
15. The olate **6** was observed in an ether extract from a mixture of **1** with H_2O (20 equiv) and concentrated HNO_3 (20 equiv) by ^1H NMR.

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