mg, 2.2 mmol) in 10 mL of EtCl was added within 25 min, and the solution was stirred for 1 h at −115 °C. Water (20 mL) was added to quench the reaction. The organic phase was separated, and the aqueous layer was extracted with two 20-mL portions of CH_2Cl_2. The combined extracts were dried ($MgSO_4$) and concentrated in vacuo. The oily products were chromatographed to give **6a** + **7a** (9 mg, 2%), **4a** (228 mg, 40%), **5a** (108 mg, 19%), and recovered **3a** (171 mg, 36%).

A Preparative-Scale Procedure of a Diels–Alder Reaction of Acrylylurea 3a with Cyclopentadiene in the Presence of $TiCl_4$ (−78 °C). To a solution of acrylylurea **3a** (2.101 g, 6.52 mmol) in 100 mL of CH_2Cl_2 was added dropwise, within 30 min under N_2 atmosphere at −78 °C, a solution of $TiCl_4$ (0.807 mL, 1.39 g, 7.34 mmol) in 20 mL of CH_2Cl_2. To the solution was added, within 15 min, a solution of cyclopentadiene (0.786 mL, 616 mg, 9.32 mmol) in 10 mL of CH_2Cl_2. Water (30 mL) was added to quench the reaction. The organic phase was separated, and the aqueous layer was extracted with CH_2Cl_2 (20 mL). The combined organic fraction was dried ($MgSO_4$) and concentrated in vacuo. The oily products were chromatographed on silica gel, by eluting with hexane/ethyl acetate (4:1) to give Diels–Alder products **4a** + **5a** + **6a** + **7a** 2.454 g (97%) and recovered **3a** (66 mg, 3%). Then the Diels–Alder adducts were separated by flash column chromatography on silica gel, eluting with hexane/ethyl acetate (9:1), to give exo adducts **6a** + **7a** (29 mg, 1%), endo adduct **4a** (1.860 g, 74%), and endo adduct **5a** (381 mg, 15%).

Methanolysis of Diels–Alder Adduct 4a. The acylurea **4a** (498 mg, 1.28 mmol) in 10 mL of methanol was added to a solution of sodium methoxide (prepared from sodium (304 mg, 13.2 mmol)) in 20 mL of methanol at 0 °C and stirred further for 8 h at 0 °C. The solution was acidified with 1 N hydrochloric acid (50 mL) and extracted with five 20-mL portions of dichloromethane. The combined organic solution was dried ($MgSO_4$) and concentrated in vacuo. The products were separated by column chromatography on silica gel, eluting with benzene–ethyl acetate (9:1), to give methyl bicyclo[2.2.1]heptene-4-carboxylate (**8**) (183 mg, 94%), recovered starting material **4a** (30 mg, 6%), and the removed urea **1** (285 mg, 83%). **8**: $[\alpha]^{22}_D$ +144.6° (c = 0.329, EtOH).[5]

Acknowledgment. We thank the fund of Mitsui Petrochemical Industries, Ltd., for a fellowship (K.K.). Thanks are also given to Kayoko Kogure for assistance in this work.

Registry No. **3a**, 119908-37-1; **3b**, 119908-38-2; **4a**, 119945-16-3; **4b**, 119908-40-6; **5a**, 119945-17-4; **5b**, 119945-18-5; **6a**, 119908-39-3; **7a**, 119945-15-2; **8**, 72203-34-0; **9**, 119908-41-7; **11**, 119908-42-8; **12**, 119945-19-6; $SnCl_4$, 7646-78-8; Et_2AlCl, 96-10-6; $TiCl_4$, 7550-45-0; $H_3CC(=CH_2)C(=CH_2)CH_3$, 513-81-5; 1,3-cyclopentadiene, 542-92-7; 1,3-cyclohexadiene, 29797-09-9; crotonic acid, 3724-65-0; acrylic acid, 79-10-7; *N,N'*-bis((*S*)-1-phenylethyl)carbodiimide, 57122-22-2.

Isolation of Stable 1:1 and 2:1 Salts of Nitrosamines with Protic Acids

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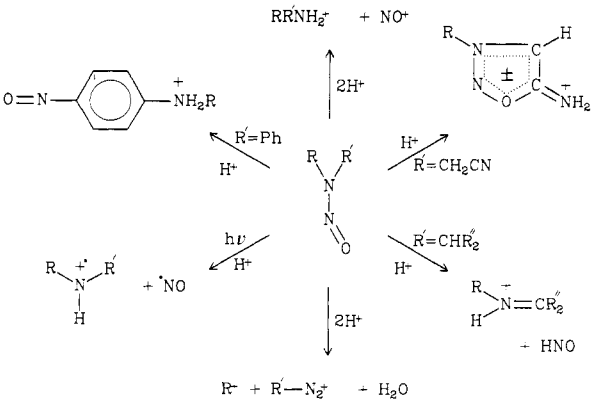
Several well-defined salts of *N*-nitroso compounds with Brønsted acids have been prepared. Both 1:1 and 2:1 adducts of nitrosamine to acid have been characterized. The former were isolated after reacting the nitrosamines with perchloric or trifluoromethanesulfonic acid and are of the form $R_2N{=}NOH^+X^-$ (X^- = ClO_4^- or $CF_3SO_3^-$). The 2:1 adducts were isolated from nitrosamine–hexafluorophosphoric acid mixtures; they have the structure $(R_2N{=}NO{---}H{---}ON{=}NR_2)^+PF_6^-$, in which two nitrosamine molecules are associated with each proton in a very strong, symmetrical hydrogen bond. The surprising stability of the salts reported here may be attributed to the use of nonnucleophilic counterions and solvents, as well as of polar media that increase the double-bond character of the N–N linkage. The practical application of these findings to the formation of crystalline derivatives of liquid nitrosamines and to the suppression of their volatility in certain synthetic and analytical procedures is discussed.

The literature to date suggests that nitrosamines are moderately to highly unstable in the presence of protic acids. While numerous N,N-disubstituted *N'*-hydroxydiazenium ions have been characterized in solution,[1-3] protonated nitrosamines are known to decompose by a variety of mechanisms (Scheme I). These include heterolysis of the N–N bond to produce ammonium ions,[3-7] cyclization of α-nitrosamino nitriles to sydnone imines,[8]

Scheme I. Some Pathways of Nitrosamine Decomposition under Protonating Conditions (see ref 3–11)



disproportionation to iminium ions and nitroxyl,[3] dissociation of the C–N linkage to yield carbocations,[3] photolysis

(1) Kuhn, S. J.; McIntyre, J. S. *Can. J. Chem.* **1966**, *44*, 105–109.
(2) Gouesnard, J. P.; Martin, G. J. *Org. Magn. Reson.* **1979**, *12*, 263–270.
(3) Olah, G. A.; Donovan, D. J.; Keefer, L. K. *J. Natl. Cancer Inst.* **1975**, *54*, 465–472.
(4) Geuther, A. *Justus Liebigs Ann. Chem.* (*Ann. Chem. Pharm.*) **1863**, *128*, 151–156.
(5) Eisenbrand, G.; Preussmann, R. *Arzneim.-Forsch.* **1970**, *20*, 1513–1517.
(6) Fridman, A. L.; Mukhametshin, F. M.; Novikov, S. S. *Russ. Chem. Rev.* (*Engl. Transl.*) **1971**, *40*, 34–50.
(7) Singer, S. S. *J. Org. Chem.* **1978**, *43*, 4612–4616.
(8) Stewart, F. H. C. *Chem. Rev.* **1964**, *64*, 129–147.

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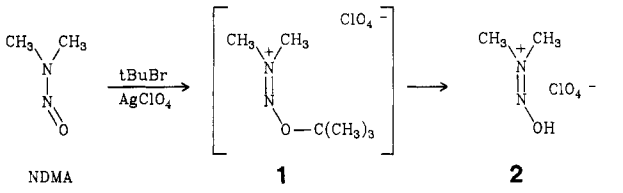
to produce aminium radicals and nitric oxide,[9,10] and the Fischer–Hepp rearrangement.[11] The N–N bond is cleaved so rapidly and completely when *N*-nitroso compounds are treated with hydrogen bromide in certain nonaqueous solvents that quantification of the resulting nitrosyl bromide is widely exploited as a group-selective assay for the nitrosamino function.[5]

Attempts to isolate well-characterized salts of nitrosamines with Brønsted acids have proven particularly frustrating. Geuther observed the transient formation of a crystalline adduct when an ether solution of *N*-nitrosodiethylamine (NDEA) was treated with dry hydrogen chloride but it decomposed rapidly and no further characterization was reported.[12] Renouf obtained similar results with *N*-nitrosodimethylamine (NDMA) although he was able to obtain a satisfactory chlorine analysis for the hydrochloride despite its tendency to decompose on standing.[13] Hantzsch and Pohl reported a satisfactory chlorine analysis for *N*-nitrosomethylaniline hydrochloride[14] but this assay does not permit the *N*-nitroso salt to be distinguished from the *C*-nitroso isomer expected to be produced on Fischer–Hepp rearrangement[11] under the acidic conditions employed.[14] Gutbier and Rausch characterized the H_2PtBr_6 salts of NDMA, NDEA, and their di-*n*-propyl and di-*iso*-butyl analogues by analyzing them for platinum but the values reported were well beyond acceptable limits for two of the salts, differing from theory by more than 2% for the dipropyl derivative.[15] More recently, Layne et al. prepared crystalline addition compounds of some 14- and 16-carbon dialkylnitrosamines with perchloric acid but the products could not be recrystallized or otherwise purified and they decomposed when warmed above 30 °C.[16]

With the aim of achieving a better understanding of the factors that determine the reactivity of nitrosamines under protonating conditions, we have been reinvestigating the acid–base behavior of these important carcinogens. We now report that in contrast to the impression of relative instability for these salts suggested in the prior literature, nitrosamine–protic acid adducts can conveniently be isolated, recrystallized, and characterized as pure, stable salts of well-defined composition.

Results and Discussion

1:1 Complexes. Our first indication that stable salts might be isolable from nitrosamine–protic acid mixtures came unexpectedly during an attempt to prepare *N'-tert*-butoxy-*N,N*-dimethyldiazenium perchlorate (**1**) as part of a systematic study of the pathways of decomposition of alkoxydiazenium ions.[17] Treatment of NDMA with *tert*-butyl bromide and silver perchlorate led to deposition of a white, crystalline product that rather rapidly decomposed on standing in solution at 25 °C. Subsequent evaporation of the solvent gave a different product that could be recrystallized from sulfur dioxide–dichloromethane. Its ^1H NMR spectrum showed only two singlets of equal intensity at δ 4.2 and 3.7 characteristic of the *N,N*-dimethyl-*N'*-hydroxydiazenium ion.[1-3] Elemental analysis (C, H, N, Cl) satisfactorily matched that expected for structure **2**, consistent with the presence of perchlorate. Identification as **2** was confirmed by dissolution in water to regenerate the nitrosamine chromophore, λ_{max} 333 nm.[16]



NDMA **1** **2**

Compound **2** proved to be remarkably stable despite the notorious oxidizing ability of perchlorate ion[18] and the explosive properties[19] of nitramines produced on oxidation of many nitrosamines.[20] The stability of **2** is exemplified by its ability to withstand the high temperatures to which it was exposed during an alternative, more convenient preparation. Neat NDMA and 70% perchloric acid were mixed in equimolar proportion and the resulting solution was concentrated to dryness in vacuo on a boiling water bath to recover **2** in high yield. Little decomposition of the recrystallized product was evident below 138–140 °C, the characteristic melting range.

Encouraged by the knowledge that such a simple process could produce a stable nitrosamine salt, we employed the same mix/concentrate/recrystallize scheme to study the fate of other acid–nitrosamine combinations. The acids

Table I. ^1H NMR Chemical Shifts of Mixtures of Dialkylnitrosamines (NA) and Brønsted Acids[a]

NA	acid	NA:acid ratio	α protons, ppm	β protons, ppm	NO–*H*, ppm
NPIP	CF_3SO_3H	1:1	4.42	1.97[b]	14.6
NPIP	CF_3SO_2H	1:2	3.90	1.97[b]	15.0[c]
NPIP	HPF_6	1:1[d]	4.29	1.90	17.8
NPYR	CF_3SO_3H	1:1	4.50, 4.18	2.34	15.0
NDMA	CF_3SO_3H	1:1[e]	4.16, 3.72		9.5
NDCA	HPF_6	1:1[d]	4.90, 4.10	1.8[f]	15.1

[a] All spectra were recorded in $CDCl_3$ except as noted. All α proton signals were multiplets except for those of NDMA. All β proton signals were multiplets, while the NO–H resonance was a broadened singlet. [b] γ protons appeared at δ 2.1. [c] Free acid proton appeared at δ 11.8. [d] CD_2Cl_2. [e] $(CD_3)_2CO$. [f] Includes γ and δ protons.

Table II. ^{13}C NMR Chemical Shifts of Mixtures of Dialkylnitrosamines (NA) and Triflic Acid[a]

NA	NA:acid ratio	α carbons, ppm	β carbons, ppm
NPIP	1:1	51.1, 58.4	25.1, 26.1[b]
NPYR	1:1	54.6, 57.5	21.9, 22.5
NPYR	1:1.5	55.4, 58.3	22.2, 22.9
NDMA	1:1	33.8, 41.3	

[a] All spectra were run in $CDCl_3$. [b] γ carbon appeared at 21.4 ppm.

(9) Axenrod, T.; Milne, G. W. A. *Tetrahedron* **1968**, *24*, 5775–5783.
(10) Chow, Y. L. *Acc. Chem. Res.* **1973**, *6*, 354–360, and references therein.
(11) Fischer, O.; Hepp, E. *Ber.* **1886**, *19*, 2991–2995.
(12) Geuther, A. *J. Prakt. Chem.* **1871**, *4*, 435–449.
(13) Renouf, E. *Ber.* **1880**, *13*, 2169–2174.
(14) Hantzsch, A.; Pohl, W. *Ber.* **1902**, *35*, 2964–2980. These authors took the yellow color of their product as evidence that the green *p*-nitroso-*N*-methylaniline was absent. The hydrochloride of the latter compound is known to be yellow, however,[11] and the conditions Hantzsch and Pohl used to prepare their yellow product were reminiscent of those used by Fischer and Hepp to induce N–C nitroso group migration in *N*-nitrosomethylaniline.[11] We conclude that some or all of the material Hantzsch and Pohl isolated could have been *p*-nitroso-*N*-methylaniline hydrochloride.
(15) Gutbier, A.; Rausch, A. *J. Prakt. Chem.* **1913**, *88*, 409–424.
(16) Layne, W. S.; Jaffé, H. H.; Zimmer, H. *J. Am. Chem. Soc.* **1963**, *85*, 1816–1820.
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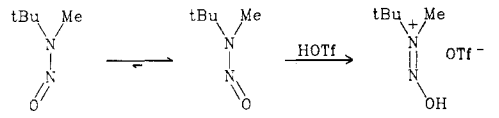
(18) Sax, N. I. *Dangerous Properties of Industrial Materials*, 6th ed.; Van Nostrand Reinhold: New York, 1984; p 2144.
(19) Lindner, V. *Kirk-Othmer Encycl. Chem. Technol., 3rd ed.* **1980**, *9*, 561–620.
(20) Emmons, W. D. *J. Am. Chem. Soc.* **1954**, *76*, 3468–3470.

employed were perchloric, trichloroacetic, trifluoroacetic, trifluoromethanesulfonic (triflic), and hexafluorophosphoric acids. The nitrosamines were NDMA, *N*-nitrosopiperidine (NPIP), *N*-nitrosopyrrolidine (NPYR), *N*-nitrosodicyclohexylamine (NDCA), *N*-nitrosomethyl-*tert*-butylamine, and *N*-nitrosothiomorpholine (NSMOR). While there was little evidence for nitrosamino group interaction with trifluoroacetic acid, interesting results were obtained with most of the other combinations. With either perchloric or triflic acid, solid, stable adducts containing 1 mol each of nitrosamine and acid could often be isolated. The properties of some 1:1 salts that could be conveniently characterized are listed in the Experimental Section. The NMR spectra of various mixtures of dialkylnitrosamines with Brønsted acids were also studied.[21] Representative ^1H and ^{13}C NMR data for these mixtures are summarized in Tables I and II, respectively. A significant feature was the apparent lack of fast proton exchange between the hydroxydiazenium ions and excess acid in chloroform-*d* or dichloromethane-d_2. In mixtures of NPIP and triflic acid, for example, the N–OH signal was the only one appearing at low field (δ 14.6) when 1 equiv of acid was present but a second sharp singlet appeared (δ 11.8) and grew larger as the triflic acid concentration was increased.

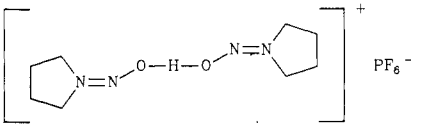
It should be noted that most of the salts we have prepared were derived from symmetrical *N*-nitroso compounds, in which both alkyl groups are the same. Attempts to extend this work to analogues in which the nitrosamino nitrogen bears two different substituents have thus far failed to yield crystalline products except for the methyl-*tert*-butyl compound, which exists almost entirely in the *E* form at equilibrium. Since other unsymmetrical nitrosamines normally consist of both *E* and *Z* conformers[22] in substantial amounts, the protonation products should be similar mixtures. It is thus not surprising that crystallization of these analogues would be more difficult.



4

2:1 Complexes. Attempts to isolate the hexafluorophosphoric acid salts of the nitrosamines also yielded nicely crystalline, sharp-melting solids, but elemental analysis data for these adducts were far removed from the results anticipated for 1:1 salts. These adducts could be recrystallized from solvents such as dichloromethane/ethyl acetate or sulfur dioxide/dichloromethane and were only slightly hygroscopic. Carefully purified samples of the salts derived from NPYR and NSMOR gave elemental analyses consistent with a composition of 2 mol of nitrosamine per mol of HPF_6. NDMA gave similar results.

We initially speculated that these adducts resulted from the dissociation of the HPF_6 to HF and PF_5, each of which coordinated with half of the nitrosamine present to form a mixed complex of the type $(R_2N^+{=}NOH)(F^-)(R_2N^+{=}NOPF_5)$.[23] This conclusion was judged unlikely when NMR spectra indicated that only one type of nitrosamine–electrophile adduct[24] was present. The presence of a "nitrosamine of crystallization" was another possible explanation for the analytical results. A single-crystal X-ray structure determination was undertaken[25] to resolve the issue. This revealed that neither of the initial hypotheses was valid. Rather, both nitrosamine molecules proved to be strongly and symmetrically coordinated to the same proton as shown in **5**.[25]



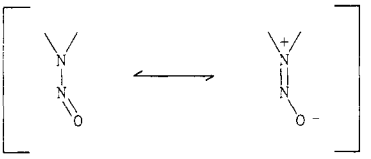
5

It is not clear why this "binitrosamine cation" should be as stable as it appears to be. NDMA has been reported to be less basic than *N,N*-dimethylformamide[1] yet the O–H bond in this nitrosamine–hexafluorophosphoric acid complex is strong enough to hold the two nitrosamines tightly and to be relatively resistant to hydrolysis (the 2:1 complexes are less hygroscopic than the 1:1 adducts). Furthermore, excess acid and ether in the initial synthesis mixture do not interfere with crystallization of the salt and the product can be recrystallized without decomposition from solvent mixtures containing ethyl acetate.

Origins of Stability in Brønsted Acid–Nitrosamine Salts. It is relevant to ask why the salts described above should be so easy to isolate, purify, and characterize when nearly all previous attempts to isolate adducts of nitrosamines with protic acids have given equivocal results or failure. There would appear to be two major reasons for our success.

Most importantly, the presence of strongly nucleophilic species has been avoided. The counterions used in the present study are much less capable of attacking the vulnerable electrophilic centers of a protonated nitrosamine than those used in previous studies (usually chloride). The use of nonnucleophilic solvents such as sulfur dioxide and halogenated hydrocarbons also appears to favor success.

The second important stabilizing influence is the presence of a high polarity medium. The dipolar resonance



form of the nitrosamino group can be expected to be favored as the dielectric constant is raised. The resulting increase in the double-bond character of the N–N linkage should result in a decreased ability of nucleophiles to displace the nitroso function. Thus, even the presence of nucleophiles may be tolerable if the medium is of sufficiently high dielectric strength. For example, NDMA survives exposure to the potential nucleophile, water, in hot, concentrated perchloric acid during the synthesis of NDMA·$HClO_4$ (see Experimental Section). This factor also provides a second advantage of sulfur dioxide as a solvent for protonated nitrosamines.

(21) The data in Tables I and II were collected by using solutions prepared by mixing the desired weights of nitrosamine and acid in an NMR tube and adding enough solvent to allow measurement. The data given in the Experimental Section for the individual compounds described therein were obtained by using solutions of the purified crystalline materials.

(22) Karabatsos, G. J.; Taller, R. A. *J. Am. Chem. Soc.* **1964**, *86*, 4373–4378.

(23) The PCl_5 addition complex of NDMA has been prepared and studied by NMR: Schmidpeter, A. *Chem. Ber.* **1963**, *96*, 3275–3279.

(24) The O–P bond in $R_2N^+{=}NOPF_5$ should be stable,[23] giving a species that is stereochemically (and presumably magnetically) distinguishable from the *N,N*-dialkyl-*N'*-hydroxydiazenium ion in the mixed complex.

(25) Keefer, L. K.; Hrabie, J. A.; Ohannesian, L.; Flippen-Anderson, J. L.; George, C. *J. Am. Chem. Soc.* **1988**, *110*, 3701–3702.

The conclusion that the stability of *N*-nitroso compounds in the presence of protic acids is favored by high polarity and low nucleophilicity is fully consistent with the prior literature. While Olah et al. have found that NDMA can survive prolonged exposure to polar superacids,[3] Eisenbrand and Preussmann have based a widely used analytical procedure on the finding that hydrogen bromide destroys *N*-nitroso compounds almost instantly in the absence of water.[5] The difference in stability between the NDMA·$HClO_4$ described above and the perchloric acid salts isolated by Layne et al.[16] might be due to the lipophilic character of the long alkyl chains in the C_{14}–C_{16} nitrosamines studied by the latter authors. Once their salt precipitates from the aqueous perchloric acid, the effective dielectric constant at the locus of the nitrosamine function must be much lower for these materials, which decompose around 30 °C, than for NDMA·$HClO_4$, which is stable at much higher temperatures. Purity may also have been a factor in this case since Layne et al. could not free their precipitates from residual perchloric acid, while the NDMA salt was easily recrystallized.

Practical Applications. The ability of nitrosamines to form stable complexes with Brønsted acids can be exploited in at least two types of organic chemical application.

In one of these, liquid nitrosamines can be converted to crystalline derivatives in a reaction that can be easily reversed to regenerate the free nitroso compound. This operation could be useful for low-temperature purification via recrystallization of heat-sensitive nitrosamines for which distillation is judged inappropriate.

In the second type of application, volatile nitrosamines can be temporarily converted to nonvolatile derivatives to facilitate their recovery from dilute solutions. This fact has been used to great advantage in preparing labeled NDMA.[26] Hydrogen isotope exchange in sodium deuterioxide/deuterium oxide followed by extraction into dichloromethane yields a relatively large volume containing a small amount of nitrosamine. Despite the 110 °C difference in boiling point, rotary evaporation of solvent leads to extensive loss (typically about half) of the NDMA. Addition of excess trichloroacetic acid followed by evaporation to dryness yields a crystalline residue that can be redissolved in aqueous medium to regenerate the nitrosamine with an overall recovery of more than 96%.[26] We have found this approach to be an advantageous alternative to Kuderna–Danish evaporation and other less convenient methods for recovering volatile nitrosamines from dilute solutions during certain synthetic and analytical operations.

Experimental Section

Warning! The strong toxicity[27] of the materials used in this investigation demands that they be handled, stored, and discarded with due respect for the possible hazards involved.

Reagents and Analytical Methods. Except as noted here, all reagents were obtained from Aldrich Chemical Company. Trichloroacetic acid was the product of Baker and Adamson (Allied Chemical). Perchloric acid was obtained from Fisher at a nominal concentration of 70%. Silver perchlorate was purchased from Alfa (Ventron). Anhydrous sulfur dioxide was from Matheson Gas Products. Ethereal hexafluorophosphoric acid was from Columbia Organics. Where necessary, the nitrosamines were prepared in house from the commercially available amines via standard nitrosation conditions.[28]

The ^1H NMR spectra were determined at 200 MHz with a Varian Model XL-200 NMR spectrometer, at 300 MHz with a Nicolet Model NT-300 instrument, at 90 MHz on a JEOL Model FX90Q, or at 60 MHz using a Varian T-60 instrument. The ^{13}C NMR spectra were recorded at 50 or 75 MHz. The chemical shifts are expressed in δ values (ppm) relative to tetramethylsilane as internal standard. Elemental analyses were performed by Galbraith Laboratories, Knoxville, TN. Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected.

Preparation of NDMA·$HClO_4$ (2). A. Via Reaction of NDMA with *tert*-Butyl Bromide and Silver Perchlorate.[17] NDMA (3.71 g, 50 mmol) and *tert*-butyl bromide (6.88 g, 50 mmol) were dissolved in 30 mL of nitromethane. Silver perchlorate (10.07 g, 48 mmol) was added as a solution in a total of 70 mL of nitromethane, inducing a mildly exothermic reaction. After standing at room temperature for 3 h, the mixture was filtered and the filtrate was evaporated in vacuo. The red-brown residue was mixed with chloroform, and the chloroform-soluble portion was evaporated. The residue was subjected to ^1H NMR analysis (acetone-d_6 solution), revealing singlets at δ 4.28, 3.95, and 1.70 in an approximate 1:1:3 ratio that were presumably due to *N'-tert*-butoxy-*N,N*-dimethyldiazenium perchlorate (1). The former two peaks were very similar in chemical shift to those for the anti and syn signals, respectively, of independently synthesized NDMA·$HClO_4$ (see below). In a second experiment, a crystalline sample of the presumed *tert*-butoxy perchlorate 1 was isolated by extracting with tetrahydrofuran the precipitate formed on reacting a mixture of 2.11 g of silver perchlorate, 0.72 g of NDMA, and 1.5 g of *tert*-butyl bromide in benzene and evaporating/cooling the tetrahydrofuran extracts. The resulting crystals were dissolved in acetone-d_6 for ^1H NMR study. The signals for the O-alkylated nitrosamine ion disappeared over time with a concomitant increase in the peaks attributed to the protonated nitrosamine. The latter assignment was confirmed by rerunning the spectrum after adding authentic NDMA to the solution, which intensified the two methyl signals in question rather than adding new peaks to the spectrum.

B. Via the Reaction of NDMA with $HClO_4$. NDMA (0.71 g, 9.6 mmol) was mixed with 1.52 g (9.3 mmol) of concentrated perchloric acid. The solution, which had lost most of its yellow color, was concentrated under reduced pressure. The resulting hygroscopic white solid was rapidly covered with CH_2Cl_2 and cooled in dry ice. Sufficient sulfur dioxide was condensed into the mixture to dissolve the solid and the solution was filtered through a glass fiber paper. The filtrate was concentrated under a stream of dry N_2 until crystallization began. The material was recrystallized twice more in this manner to yield 0.6 g (27%) of product as fine white needles, mp 138–140 °C dec: ^1H NMR (200 MHz, acetone-d_6) 3.72 (3 H, s, syn protons), 4.16 (3 H, s, anti protons), 9.5 (1 H, s); ^{13}C NMR (acetone-d_6) 33.76, 41.35.

Anal. Calcd for $C_2H_7O_5N_2Cl$: C, 13.76; H, 4.04; N, 16.04; Cl, 20.31. Found: C, 13.64; H, 4.14; N, 16.13; Cl, 20.55.

Preparation of NPYR·$HClO_4$ (3). To 0.2 g (2.0 mmol) of NPYR under N_2 was added 0.15 mL (2.4 mmol) of concentrated aqueous $HClO_4$ dropwise. White crystals formed immediately, 5 mL of CH_2Cl_2 was added, and the two-phase mixture was dried with $MgSO_4$. Concentration under a stream of N_2 afforded a white powder, which was recrystallized from CH_2Cl_2/ether to yield 0.12 g (30%) of white platelets, mp 118–120 °C dec: ^1H NMR (90 MHz, CD_2Cl_2) 2.1 (4 H, m), 3.8 (2 H, m), 4.26 (2 H, m), 17.6 (1 H, s); ^{13}C NMR (CD_2Cl_2) 22.0, 23.0, 51.0, 54.0.

Anal. Calcd for $C_4H_9ClN_2O_5$: C, 23.96; H, 4.49; N, 13.97; Cl, 17.68. Found: C, 24.06; H, 4.70; N, 14.01; Cl, 16.19.

Preparation of the Triflic Acid Salt of *N*-Nitrosomethyl-*tert*-butylamine (4). A solution of *N*-nitrosomethyl-*tert*-butylamine (0.23 g, 1.5 mmol) in 5 mL of CH_2Cl_2 was cooled in an ice bath. To this was added 0.18 mL (2.0 mmol) of trifluoromethanesulfonic acid dropwise over 30 min. The solvent was evaporated under a stream of N_2. The residual powder was recrystallized from CH_2Cl_2/ether, affording 0.20 g (43%) of white crystals, mp 60–62 °C dec: ^1H NMR (300 MHz, CD_2Cl_2) 1.65 (9

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H, s), 3.80 (3 H, s), 17.0 (1 H, very broad s); ^{13}C NMR (CD_2Cl_2) 28.9, 37.8, 122.3.

Anal. Calcd for $C_6H_{13}F_3O_4N_2S$: C, 27.04; H, 4.92; F, 21.40; N, 10.52. Found: C, 27.02; H, 5.00; F, 17.39; N, 10.39.

Preparation of (NPYR)$_2$·HPF$_6$ (5). A solution of HPF_6·Et_2O (2.18 g, 9.9 mmol) in dichloromethane was prepared and to this was added 0.96 g (9.6 mmol) of NPYR. The resulting solution was filtered and diluted with ethyl acetate until a white precipitate had formed. The product was recrystallized three times from CH_2Cl_2/ethyl acetate to yield 0.19 g (6%) of product as white platelets, mp 118-122 °C dec: ^1H NMR (90 MHz, CD_2Cl_2) 2.19 (8 H, m), 3.87 (4 H, m), 4.34 (4 H, m), 17.0 (1 H, s); ^{13}C NMR ($CDCl_3$) 23.0, 24.0, 50.0, 53.0.

Anal. Calcd for $C_8H_{17}F_6N_4O_2P$: C, 27.75; H, 4.95; N, 16.18; P, 8.94. Found: C, 27.50; H, 5.14; N, 16.41; P, 9.20.

Preparation of (NSMOR)$_2$·HPF$_6$ (6). A solution of HPF_6·Et_2O (1.74 g, 7.9 mmol) in dichloromethane was mixed with 1.08 g of NSMOR (8.2 mmol) at room temperature and a stream of N_2 was passed over this solution until precipitation began. The cold CH_2Cl_2 was decanted and the residue was taken up in 10 mL of liquid sulfur dioxide. Filtration followed by the addition of CH_2Cl_2 and concentration to one-half volume led to the deposition of off-white platelets, which were again recrystallized from SO_2/CH_2Cl_2 to yield 0.46 g (27%) of white platelets, mp 81-83 °C dec: ^1H NMR (90 MHz, CD_2Cl_2) 1.9 (8 H, m), 4.29 (8 H, m), 17.8 (1 H, s); ^{13}C NMR (CD_2Cl_2) 25.7, 26.8, 47.5, 56.2.

Anal. Calcd for $C_8H_{17}F_6N_4O_2PS_2$: C, 23.41; H, 4.17; N, 13.65; P, 7.59; S, 15.62. Found: C, 23.13; H, 4.22; N, 13.56; P, 7.81; S, 15.90.

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Kinetic Study for Reactions of Nitrate Radical (NO_3·) with Substituted Toluenes in Acetonitrile Solution

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The absolute rate constants for the reactions of the nitrate radical (NO_3·) with substituted toluenes in acetonitrile have been determined by the flash photolysis method. From the plots of the rate constants against the ionization energies, it was revealed that the reaction path for toluene derivatives with low ionization energies is different from that for toluene derivatives with high ionization energies. For toluene, a deuterium isotope effect was observed to be ca. 1.6, suggesting the direct hydrogen atom abstraction reaction; in this group, xylenes and *p*-chlorotoluene belong. For toluene derivatives with electron-withdrawing substituents, NO_3· may add to the phenyl rings followed by successive reactions. For both groups, linear correlations against the ionization energies with negative slopes show that NO_3· is highly electrophilic and that strong polar effects exist in the transition states of both reactions. For toluenes with methoxy groups, the electron-transfer reaction from methoxytoluene to NO_3· is a main initial path, since the transient absorption band due to the cation radical of methoxytoluene was detected.

Introduction

Photochemical reaction of $(NH_4)_2[Ce(NO_3)_6]$ with toluene derivatives ($ArCH_3$) in acetonitrile yields side-chain nitroxydation products in high yields.[1,2] For the initial

$$ArCH_3 \xrightarrow[\text{in acetonitrile}]{h\nu,\ (NH_4)_2[Ce(NO_3)_6]} ArCH_2ONO_2 \qquad (1)$$

step of this reaction, participation of NO_3· produced by the photolysis of $[Ce(NO_3)_6]^{2-}$ has been confirmed by flash

$$[Ce(IV)(NO_3)_6]^{2-} \underset{k_b}{\overset{h\nu}{\rightleftharpoons}} NO_3\cdot + [Ce(III)(NO_3)_5]^{2-} \qquad (2)$$

photolysis method.[3,4] Since NO_3· is known to be a strong oxidizing reagent as well as a hydrogen-atom abstracting reagent, the following two reactions would be anticipated:

$$NO_3\cdot + ArCH_3 \rightarrow ArCH_2\cdot + HNO_3 \qquad (3)$$

$$NO_3\cdot + ArCH_3 \rightarrow ArCH_3\cdot^+ + NO_3^- \qquad (4)$$

$$\downarrow$$

$$(ArCH_2\cdot + H^+)$$

It was presumed that the final product ($ArCH_2ONO_2$) was formed after further oxidation of $ArCH_2$· to $ArCH_2^+$ with $[Ce(NO_3)_6]^{2-}$ followed by the reaction with NO_3^-.[5]

For toluene derivatives with electron-donating substituents such as a methoxy group, the electron-transfer process (reaction 4) was confirmed by the laser flash photolysis method.[4] For toluene itself, however, there remains a possibility for the direct hydrogen-atom abstraction (reaction 3) with highly polar transition state. Furthermore, for toluene derivatives with electron-withdrawing substituents, the other initial reaction steps can be considered, since the high addition ability of NO_3· to phenyl π-bonds was assumed in the gas-phase reaction of NO_3· with phenol and furan.[6,7]

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