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Highly efficient Friedel–Crafts-type benzylation *via* benzyl cations generated in multiple spacer-molecule separated ion-pairs †

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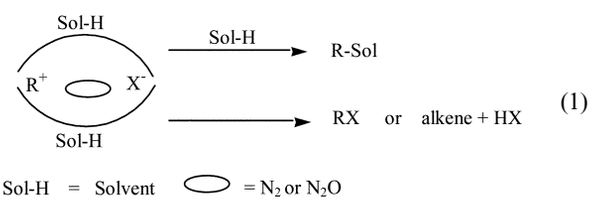
Deamination, as a facile route to highly reactive carbocations, is of interest to several areas of organic chemistry, industry, and medicine. The reactivity and utility of these carbocations derives from the presence of a lone nitrogenous entity (N_2 or N_2O) interposed between the ion-pair. We report here the synthesis of a new deamination precursor whose nitrosation and subsequent decomposition constitutes a novel deamination method. In this novel approach, multiple spacer-molecules are generated in the inter-ion space. The resultant cations are exceedingly reactive but are longer-lived than carbocations derived from standard deaminations. The result is nearly quantitative yields of solvent-derived products from even poorly nucleophilic solvents such as benzene, toluene, and mesitylene.

Introduction

The standard Friedel–Crafts (F–C) alkylation of aromatic compounds is a Brønsted or Lewis acid-catalyzed reaction of an aromatic substrate with alkyl halides, alkyl esters of strong acids, with alcohols, or with unsaturated compounds. This versatile reaction has wide synthetic use and its mechanism continues to be the subject of lively debate.[2,3b] The central mechanistic questions surrounding the F–C reaction deal with the identity of the electrophile, the kinetics of the formation of the arene–electrophile σ-bond, the presence of defined and directed intermediates preceding the arenium ion and the source of the *meta* isomer.

Darbeau *et al.* have utilized deamination chemistry as a means of elucidating the details of the bond-forming step of the F–C reaction as well as in tracing the origin of the mechanistically important *meta* isomer.[3b] These deaminative F–C alkylations involved the generation of poorly complexed phenylcarbenium ions (benzyl cations) in equimolar benzene/toluene mixtures *via* thermolyses of *N*-4-R-benzyl-*N*-nitrosoamides and *via N*-4-R-benzyl-*N*-nitroso-*O*-acylhydroxylamines.

Deamination generates highly reactive carbocations as part of a nitrogenous entity separated ion-pair [NESIP; eqn. (1)].[3–7] Their high reactivity[3–7] arises from the low activation energy required for the loss of N_2 (or N_2O) from the alkyldiazonium (or related) precursor allowing the cation to be formed with minimal solvent participation.[3–7] Additionally, the temporary screening of the cation from its counterion by the sheer physical presence of the nitrogenous entity results in the maximal positive charge at the electron-deficient center.[3a,b,8]



(1)

Because the reaction occurs in solution, the nascent nitrogenous entities between the ions are not gases upon generation. They form gases, however, when very large numbers of their molecules gather upon escape from the various solvent cages in which the unimolecular thermolyses occur. Nitrogenous entity formation is relevant because these species are believed to (1) serve as inert "spacer molecules" between the gegenions, (2) exert an enthalpic pull on the forward reaction as a result of their inherent stability, (3) exert an entropic pull on the forward reaction, and (4) essentially negate the likelihood of a reverse reaction because their mobility and ease of escape from the solvent cage makes them unlikely to remain in a favorable geometry for recombination.

When the carbocation *e.g.*, the benzyl cation, is stabilized and devoid of β-hydrogens, S_N1-type reaction with the counterion or the solvent is its only fate.[3,5–7] Cation–solvent reactions are believed to occur prior to diffusion of the nitrogenous entity from between the ions in the solvent cage since the latter process is thought to lead to essentially instantaneous internal collapse of the ion-pair to give the corresponding ester.[4a] Thus, the nitrogenous entity is implicated in the partitioning of the carbocation between its nascent counterion and the medium; the longer it remains in the pocket between the ions, the more opportunity is afforded the carbocation to interact with the medium.[3–7] If the reactivities of the carbocation and solvent have reached some threshold level for reaction,[9a] then such extended carbocation–solvent interaction could lead to enhanced yields of products derived from the solvent.

Solvent-derived products from deamination

The yield of solvent-derived products (SDPs) increases with the reactivity of the cation,[3c] with the mole fraction and nucleophilicity of the active solvent,[3c] and in an inverse manner with the nucleophilicity of the counterion.[3c] The yield of SDP also generally rises, but to a lesser extent, with decreasing temperature[3c] and when the nitrogenous molecule = N_2O rather than N_2.[3c] The latter observation relates to the present work (*vide infra*) and is believed to arise from greater shielding of the cation from the counterion by the more massive N_2O and a more lethargic departure by this heavier molecule[9c] allowing the cation more opportunity to interact with the solvent.[3]

The utility of deamination

Deamination is a useful method of preparation for products of industrial (*e.g.* high-melting polystyrene),[5] synthetic (*e.g.* monoalkylated heteroaromatics,[3d] mixed diacylamines,[3e,6] and stable onium ion salts),[3e,4b,6] and medicinal (*e.g.* cancer chemotherapeutic agents)[7c] importance.[3,5,6,7c] The technology has also been applied successfully to physical organic studies including examination of the bond-forming step of the Friedel–Crafts

† Hyperdeamination chemistry. Part 1.[1]

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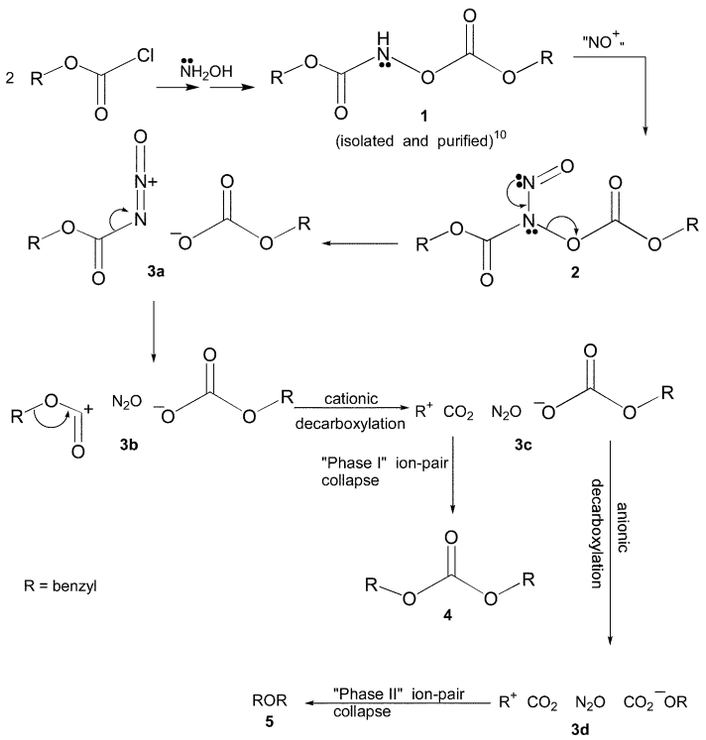


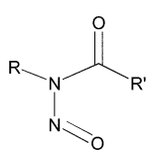
Scheme 1 Potential decomposition pathways for *N*-nitroso-*N*-carbobenzoxy-*O*-carbobenzoxyhydroxylamine showing two phases of ion-pair collapse.

reaction,[3a,b] the Brown Selectivity Relationship,[3a,b] to the novel *N*-nitrosoamide-mediated Ritter-type reaction,[6b,c] and most recently, to the postulation of new subclasses of steric, orbital, and electronic effects.[7d]

The utility of deamination arises from the ability of the highly reactive carbocations to be scavenged by solvents possessing π- and/or n-electron pairs. Such carbocation–solvent interactions are limited partially[8a] by the lifetime of the carbocation.[3–7] Presumably, if the carbocation's lifetime is extended by delaying internal collapse, then carbocation–solvent interaction would proceed for longer leading to more SDPs and enhancement of deaminative technology. Further, since the shielding of the cation from its gegenion increases through generation of the bulkier, heavier N_2O *vs.* N_2 (*vide supra*)[3c,10b] then, if more than one spacer molecule is generated between the ions, they should collectively provide better inter-ion shielding presumably due to the greater volume occupied by the spacer molecules and the increased inter-ion distance, among other factors.[9d] More time would be needed for diffusion of multiple spacer molecules from between the ions resulting in enhanced opportunity for carbocation–solvent interaction (= larger yields of SDPs). Thus a "multi-spacer" deamination ("hyperdeamination") would be of special use where the intent is derivatization of relatively inert solvents.

We report here the synthesis of the deaminative precursor: *N*-carbobenzoxy-*O*-carbobenzoxyhydroxylamine (**1**).[10a,b] This compound was chosen because it should be readily *N*-nitrosated (by "NO^+", N_2O_4, or nitrosyl halides, *etc.*) to derive its *N*-nitroso-derivative (**2**). The species **2** is structurally comparable to both *N*-nitrosoamides (**6**) and *N*-nitroso-*O*-acylhydroxylamines (**7**) and could potentially decompose along either, or both, deaminative pathways. However, the greater lability of *N*-nitroso-*O*-acylhydroxylamines (these compounds spontaneously deaminate even at −100 °C)[3c] over *N*-nitrosoamides (some of which have half-lives on the order of months at 25 °C)[3c] suggests that the activation energy for decompositions of the former is much lower. Consequently, decomposition was expected to occur as in Scheme 1.

The formation and decomposition of **2** were performed in benzene-d_6, toluene-d_8, and mesitylene-d_{12}. The presence of



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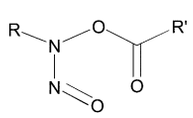
6a: R = $PhCH_2$, R' = ^{t}Bu



7

7a: R = $PhCH_2$, R' = Ph

SDP = diphenylmethane (DPM; from reaction in benzene), the isomeric methyldiphenylmethanes (MeDPMs; from reaction in toluene), of benzylated mesitylene (BM; from reaction in mesitylene) was determined by ^{1}H NMR spectroscopy by examining the signals for the benzylic methylene groups. The presence of Phase I and Phase II products [Scheme 1; dibenzyl carbonate (**4**) and dibenzyl ether (**5**), respectively] from internal collapse were determined in like manner.

N-Carbobenzoxy-*O*-carbobenzoxyhydroxylamine (**1**) was prepared by treatment of *N*-carbobenzoxyhydroxylamine[12a] (NCH) with 1.1 equivalents of benzyl chloroformate (BCF) in methylene chloride in the presence of vacuum-dried $NaHCO_3$.[11] NCH, itself was prepared from the reaction of hydroxylamine and 1.2 equivalents of BCF in CH_2Cl_2 with $NaHCO_3$ present, as above. Solutions of recrystallized (ether/hexane) **1** in each of the anhydrous arenes were treated with ~0.5 equivalents of $NO^+SbF_6^-$ under argon at 21 °C; the reactions were quenched after 75 minutes of vigorous agitation by washing with saturated $NaHCO_{3(aq).}$[12b] The products of the reactions (Table 1) are those from internal collapse (*vide supra*, Scheme 1): **4** (δ 4.79–5.06),[12c] and **5** (δ 4.31–4.81);[12c] the SDPs from the arenes are DPM (δ 3.72), MeDPMs (δ 3.74), and BM (δ 3.84).

The data (Table 1) show the product distributions from thermolysis of *N*-benzyl-*N*-nitrosopivalamide (**6a**; nitrogenous entity = N_2), nitrosation of *N*-benzyl-*O*-benzoylhydroxylamine [**7**; spacer molecule (= nitrogenous entity) = N_2O],[3h] and *N*-carbobenzoxy-*N*-nitroso-*O*-carbobenzoxyhydroxylamine [**2**; spacer molecules = N_2O + nCO_2; n = 1 or 2 (*vide supra*)]. The relatively small disparity in the yields of SDP between the deaminations of **6a** and **7** has been accounted for in terms of

Table 1 Yield[a] of solvent-derived product from deaminative and hyperdeaminative benzylation of selected arenes

Precursor	Deamination mode	Temp (°C)[b]	Spacer molecule(s)	% Solvent-derived product		
				Benzene	Toluene	Mesitylene
6a[c]	normal	20	N_2	7.5	16.3	28.2
7[d]	normal	25	N_2O	8.4	21.6	
2[e]	hyper	21	$N_2O + nCO_2$[f]	98.7	99.5	99.6

[a] Data are averages of at least duplicate runs. % SDP + % ion pair collapse is taken as = 100% (trace unknowns 2%, in some runs). [b] Although the yield (std. dev. 0.3) of solvent-derived product falls with decreasing temperature (ref 3*c*), the change is small and is not likely to be expressed over a 5 degree range. [c] *N*-Benzyl-*N*-nitrosopivalamide was used. [d] *N*-Benzyl-*N*-nitroso-*O*-benzoylhydroxylamine was used. [e] *N*-Carbobenzoxy-*N*-nitroso-*O*-carbobenzoxyhydroxylamine was used. [f] One and or two CO_2 molecules are generated here.

the greater spatial and temporal shielding of the benzyl cation from its gegenion by the larger, heavier N_2O *vs.* N_2.[3a–c,h,10c]

The huge difference in hydrocarbon yield between the hyperdeaminative and the standard deaminative cases (even with N_2O rather than N_2 as the spacer molecule) is staggering. The enhanced yield of SDP suggests that (1) the hyperdeaminatively generated benzyl cation is far more reactive than its deaminative counterpart[1] and/or (2) the cation is longer-lived and has more time for solvent–cation interaction leading to SDP. Both of these hyperdeaminative properties arguably arise from greater shielding of the cation from its nascent counterion. Thus, we propose that the presence of these multiple spacer molecules reduces the stabilizing cation/counterion ionic interaction resulting in the essentially uncomplexed, highly reactive species observed.[1]

Additionally, the greater cation/counterion shielding by the multiple spacer molecules in the inter-ion space militates against cation/counterion approach within bonding distance. In this way, the spacer molecules impose significant steric hindrance to ion-pair collapse. The cumulative result then is the formation of highly uncomplexed cations that are afforded extended time for cation–solvent interaction resulting in the enhanced yields of SDP observed. It should be noted that the intuitive concept regarding the reactivity of an intermediate requires that highly reactive species should exist for a short time. It would appear that in the hyperdeaminative case this inverse relationship between the cation's reactivity[1] and lifetime may not hold.

Table 1 shows that in the deaminative series *via* the nitrosoamide, there is a 117% increase in SDP on going from benzene to the more nucleophilic toluene. The yield of SDP increases by a further 73% when the reactions are performed in mesitylene rather than toluene. The implication therefore is that the deaminatively generated cations are able to discern between solvents of differing nucleophilicity. However, in the hyperdeaminative case, there is less than a 1% change in % SDP as the solvent is varied from benzene to toluene to mesitylene indicating that the hyperdeaminatively generated carbocations are essentially incapable of distinguishing between the nucleophilicities of these three solvents. It would appear then that the hyperdeaminatively-generated cation's lifetime/reactivity imposes a leveling effect on the solvent nucleophilicity.

Based upon *N*-nitrosoamide decomposition in acetic acid,[4c] methanol,[3h] and pyrrole,[3d] we have previously argued that a minimum of 20% of carbocations in NESIPs are committed to internal collapse with their nascent counterions.[3d] This commitment to ion-pair collapse is evidently absent in the hyperdeaminative case due to the electronic shielding and steric hindrance imposed by multiple spacer molecules between the ion-pair.

The near quantitative alkylation of solvent by hyperdeaminative-generated benzyl cations as reported here is not unique and has been reported by other workers such as Maskill *et al.*[13a–c] Indeed in the Maskill cases[13a–c] very large yields of solvent-derived products (SDP) arise from the generation of such cations in appropriate aqueous solvents. However, in those studies, the counterions are sulfonates and the solvent is either an aqueous alcohol or aqueous acetonitrile.[13d] In these scenarios, extremely high yields of SDP must occur for the following reasons (1) the extremely poorly nucleophilic sulfonates do not efficiently compete against the nucleophilic solvent for the capture of the carbenium ions, consequently, (2) the nucleophilic solvent almost completely captures the carbocation. Further, (3) although some carbocations may collapse into the sulfonates, this reaction produces the very labile benzyl sulfonate esters which in the presence of the highly polar (and nucleophilic) solvent systems employed by Maskill[13] are strongly predicated to subsequent S_N phenomena to yield even more SDP. The net result is that in the Maskill system it is not surprising that extremely high yields of SDP are observed because solvent alkylation stems from the presence of an aggressive solvent capturing both first and second generation benzyl electrophiles.

The Maskill studies[13a–c] are mentioned here because they bear a tangential similarity to the present work. However, they do not directly compare to the present work because in our studies the counterions are the much more nucleophilic carbonates and/or alkoxide and the cations are generated in solvents of comparatively very low nucleophilicity and polarity. Consequently, efficient and irreversible trapping of the cations by the counterions might be expected to occur in our system leading to low yields of SDP (indeed in *N*-nitrosoamide thermolyses in benzene, this is the case). Yet, in the present study not only is the yield of SDP high, it is nearly quantitative. Without the advantages of the Maskill system, therefore, a new explanation must be found for the tremendous yield enhancement observed.

The central thrust of this report is that the carbocation generated here is so well shielded (physically = spatially and temporally)[9d] from its counterion that it is almost completely constrained against interacting with it and therefore to near specificity in its reactions with even poorly nucleophilic solvents. This is a marked change in behavior from the N_2- and N_2O-separated ion pairs where even though N_2O provides better shielding and escapes more slowly from the inter-ion space than N_2, the change in %SDP is much smaller than observed between the hyperdeaminative and deaminative cases. (Table 1).

Internal collapse products from hyperdeamination

Although the mechanistic details of the reaction are yet to be fully elucidated, the product distribution and analogies to the established chemistry of *N*-alkyl-*N*-nitroso-*O*-acylhydroxylamines suggest the following sequence of events. The decomposition of **2** evidently occurs by fragmentation of the labile N–O hydroxylamino bond to generate the intimate ion pair **3a**. Dediazoniation of **3a** yields an N_2O-separated ion pair **3b**, the carboxylium ion of which undergoes cationic decarboxylation to derive a double-spacer molecule separated ion pair **3c**. It is to be expected that fission of the carboxylium ion would be facile because of resonance stabilization in the benzyl cation and

Table 2 Product distribution[a] from hyperdeaminative benzylation[b] of selected arenes at 21 °C

Solvent	% Solvent-derived product	% Internal collapse products	
		Phase I	Phase II
Benzene	98.7	1.2	trace
Toluene	99.5	0.5	0.0
Mesitylene	99.6	0.4	0.0

[a] Data are averages of at least triplicate runs (std. dev. 0.3). % SDP + % ion pair collapse is taken as = 100% (trace unknowns 2%, in some runs). [b] *N*-carbobenzoxy-*N*-nitroso-*O*-carbobenzoxyhydroxylamine was used.

because CO_2 formation is both enthalpically and entropically favored. The carbocation in **3c** has the options of reacting with solvent and collapsing with the alkyl carbonate ion to form dibenzyl carbonate **4** (Phase I ion-pair collapse; Scheme 1). Some alkyl carbonate ions that avoid capture by the first generation cation undergo anionic decarboxylation to generate the triple molecule separated ion pair, **3d**. This fission converts the poorly basic alkyl carbonate anion into the strongly basic alkoxide, but probably progresses largely due to the negative enthalpy and positive entropy changes associated with CO_2 formation.[14a] Nonetheless, it is to be expected that this second decarboxylation is somewhat less facile than the former. The second generation cation in **3d** may undergo Phase II ion-pair collapse into dibenzyl ether, **5** or may react with solvent to form SDP. The relative yields of SDP and Phase I and Phase II products (Scheme 1) are shown Table 2.

The larger yield of **4** *vs.* **5** may indicate that (1) **3c** is more abundant than **3d** implying that the anionic decarboxylation is slow relative to ion-pair collapse of **3c**. Alternatively, (2) ion-pair collapse in **3d** may be prohibitively slow relative to collapse in **3c** due ostensibly to greater inter-ion shielding in the latter. It would appear that benzylation of the solvent occurs *via* two hierarchies of highly reactive benzyl electrophiles with the second generation being exceedingly reactive. Quantification of the roles of each generation of benzyl electrophile in solvent derivatization is currently being investigated in our laboratory.

Nitrosation of *N*-carbobenzoxy-*O*-carbobenzoxyhydroxylamine (1) in hexane

Compound **1** was nitrosated *via* $NOSbF_6$ in hexane-d_{14} with vigorous agitation. Decomposition of the nitroso-derivative (**2**) in an inert solvent excludes the pathway leading to SDP, consequently the only fate available to the carbocation is the relatively slow ion pair collapse. This decomposition in an inert medium allows for the determination of the relative amounts of Phase I and II ion-pair involvement in product formation. The data show the formation of 83% dibenzyl carbonate (**6**) and 17% dibenzyl ether (**7**). This result is significant, because it indicates that the initial cationic decarboxylation, which leads to the Phase I separated ion pair (Scheme 1), is more facile than the subsequent anionic decarboxylation, which leads to Phase II separated gegenions (Scheme 1).[14b] Also these results mean that all of the data from the decompositions in the arenes (*vide supra*) are weighted averages, of the double- and triple-spacer molecule separated ion-pairs.

It should be pointed out here that under ideal circumstances, parallel reactions in solvents of varying bulk properties (*e.g.*, polarity, hydrogen-bonding ability, *etc.*) would have been conducted to determine whether the 83 : 17 apportioning of reactions *via* Phase I/Phase II ion-pairs was solvent dependent. Unfortunately, the choice of solvent for this investigation was severely limited because polar solvents would possess n-pairs of electrons and since the carbocations are able to intercept the reluctant π electrons of benzene, they would be expected to interact with the n- and π-containing systems of haloalkanes, alcohols, carbonyls, *etc*. Further, nucleophilic solvents may also be subject to nitrosations leading to side products or labile intermediates[13d] that would complicate the reaction.

Conclusion

We have presented evidence of a facile, novel deaminative method. This "*hyperdeaminative*" mode evidently generates carbocations that are longer-lived and perhaps even more reactive than those generated *via* standard deamination.[1] At this point we cannot state whether the spacer molecules have a greater effect on cation lifetime or inherent reactivity, however, it is clear that the confluence of enhanced lifetime/reactivity results in extremely efficient solvent capture of even poorly nucleophilic arenes. The technique would appear to be ideal for derivatization of solvents of low nucleophilicity. Evidently the enhanced lifetime/reactivity of the hyperdeaminatively generated carbocations derives from the electronic insulation of the carbocation from the stabilizing effects of its native counterion, from severe steric hindrance to ion-pair collapse, and from increased opportunity for carbocation/solvent interaction.

Experimental

Materials and methods

All commercially available reagents were reagent grade and were used without further purification. All moisture sensitive experiments were performed in a glovebox, which had been purged exhaustively with ultra high purity argon. Chemical shifts in the ^{1}H NMR spectra are reported in ppm downfield from internal TMS. Spectra were obtained on JEOL Eclipse$^+$ 300 MHz FT-NMR, Perkin Elmer 1600 Series FT-IR and Beckman Model 25 UV-Vis. All syntheses and reactions of *N*-nitrosoamides were performed in the dark; in many instances, reactions were performed in evacuated sealed NMR tubes. Elemental analyses were performed by Quantitative Technologies Inc.

Handling and storage of *N*-benzyl-*N*-nitrosopivalamide (NBNP)

N-Nitrosoamides are thermolabile, photolabile, and unstable in the presence of acids, bases, and moisture, therefore they are stored in dry vials under an inert gas, and in a cryogen dewar containing liquid nitrogen. NBNP must be stored and handled in the dark. **Caution!** Nitrosoamides should be handled with extreme care due to their possible mutagenicity[15a] and carcinogenicity (local and systemic).[15b] Efficient fume hoods and appropriate personal protective equipment (chemical resistant gloves, safety glasses, lab coat, *etc.*) should be used when handling these types of compounds.

N-Carbobenzoxyhydroxylamine (NCH)

This compound was prepared by free-basing the hydroxylamine hydrochloride salt with an excess of sodium bicarbonate in 100 ml of methylene chloride, with vigorous stirring for ~15 minutes. Then 1.2 eq. of benzyl chloroformate (BCF) was added to the reaction vessel and allowed to react overnight at room temperature. After 24 hours the solution was vacuum filtered to remove the sodium bicarbonate. The bulk solvent was removed by rotary evaporation, and then the solution was taken to complete dryness using a high vacuum pump. The solid residue consisted of the monocarbobenzoxylated hydroxylamine, *N*-carbobenzoxy hydroxylamine (NCH). The NCH was then recrystallized using ether and hexane. NCH is hydrolyzable, the dry neutral solid is stored under N_2: mp 62–64 °C (lit: 65–70).[16a] IR (KBr) 3373, 3300, 1703, 1502, 1398, 1288, 1119 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 5.19 (s, 2H), 5.89 (s, 1H), 7.21 (s, 1H), 7.36 (s, 5H). Anal. Calcd for $C_8H_9NO_2$: C, 57.5; H, 5.4; N, 8.4; O, 28.7. Found: C, 57.8; H, 5.4; N, 8.3; O, 28.4%.

N-Carbobenzoxy-*O*-carbobenzoxyhydroxylamine (1)

The purified NCH was then redissolved in methylene chloride and an excess of sodium bicarbonate, and 1.1 eq. of BCF were added. The reaction was left stirring at room temperature overnight. The solution was then filtered, solvent was removed, and **1** was recrystallized using the procedure described. Compound **1** is hydrolyzable and therefore should be stored in a sealed container, under an inert gas (nitrogen or argon), and placed in a desiccator: mp 72–74 °C. IR (KBr) 3221, 1805, 1716, 1506, 1244, 1146 cm^{-1}; ^1H NMR ($CDCl_3$) δ 5.23 (s, 2H), 5.26 (s, 2H), 7.35 (s, 10H), 7.88 (s, 1H). Anal. Calcd for $C_{18}H_{15}NO_5$: C, 63.8; H, 5.0; N, 4.6; O, 26.6. Found: C, 63.7; H, 4.9; N, 4.6; O, 26.4%.

Nitrosation and decomposition of compound 1

The nitrosation of compound **1** was performed under an inert argon atmosphere in a glove box. Due to the highly hygroscopic nature of the nitrosating agent, precautions were taken to minimize the likelihood of corrupting the dry inert environment. Prior to the introduction of any glassware into the glove box, the glassware was vacuum dried overnight at 80 °C. Approximately 23 mg of **1** were placed into labeled individual 16 ml teflon-lined screw top vials. The samples were vacuum-dried overnight.

The solvent containers, benzene-d_6, toluene-d_8, and mesitylene-d_{12}, were opened in the glove box. The solvents were then dried over sodium sulfate for 30 minutes. 1.5 ml of the appropriate solvent was then pipetted into each of the screw top vials containing the samples of **1**. The vials were then shaken until all of **1** had dissolved, forming a ~0.05 M solution. Approximately 10.2 mg of nitrosonium hexafluoroantimonate ($NOSbF_6$) was weighed out into a labeled screw top vial; the 0.05 M solution of **1** was then pipetted into the vial containing the $NOSbF_6$. Upon addition of the solutions of benzene-d_6, toluene-d_5, and mesitylene-d_{12}, the solutions changed from colorless to pale yellow, deep yellow, and orange/rust color, respectively. The vials were sealed and removed from the glove box and agitated vigorously on a multiple wrist shaker for 75 minutes at 21 °C. The solutions were quenched using a saturated sodium bicarbonate solution, in order to neutralize any unreacted $NOSbF_6$. The organic layer was then collected, sealed in a screw top vial, placed in a desiccator, and refrigerated at −20 °C until the analysis could be performed. Chloroform-*d* extractions were performed on the aqueous samples and analyzed *via* ^1H NMR to insure that no reaction products were present. All decompositions were run in triplicate.

N-Benzylpivalamide

N-Benzylpivalamide was prepared from the method of Heyns and von Bebenburg:[16b] mp 81–82 °C (lit[16c] mp 81–82 °C); IR (KBr) 3309, 1689, 1510, 1390, 1375 cm^{-1}; ^1H NMR ($CDCl_3$) δ1.27 (s, 9H), 4.44 (d, 2H, J = 7 Hz), 5.90 (bs, 1H), 7.26–7.32 (m, 5H); UV (Et_2O) λ_{max} = 284 nm (ε = 209).

N-Benzyl-*N*-nitrosopivalamide (NBNP)

A mixture of *N*-benzylpivalamide (9.5 g, 50 mmol), NaOAc (25 g, 0.3 mol) and Na_2SO_4 (50 g) was dried at oil pump vacuum. Chloroform (300 cm^3) freshly distilled from P_2O_5, was added to the solid material (under N_2) and the suspension was cooled to −78 °C. A solution of N_2O_4 (l) (20 cm^3, 0.31 mol) in $CHCl_3$ (100 cm^3) at −78 °C was then added to the stirred suspension at −78 °C which was then allowed to warm to −25 °C over 10 min. After a further 15 min at −25 °C, the suspension was evaporated *in vacuo* for ~15 min until a lemon yellow color was observed. Ether at −20 °C was then added and the suspension was washed in turn with saturated solutions of NaCl, Na_2CO_3 and NaCl at −5 °C. The organic phase was dried over Na_2SO_4 at −30 °C then evaporated *in vacuo* (at −30 °C) to yield 11 g (50 mmol, 100%) of a lemon yellow oil. The synthesis and isolation were performed in the dark: IR (neat) 1720, 1605, 1502, 1390, 1375 cm^{-1}; ^1H NMR (CD_3CN) δ 1.45 (s, 9H), 4.97 (s, 2H), 7.05–7.40 (m, 5H); UV (CH_2Cl_2) λ_{max} 275 nm (ε = 500), 400 nm (ε = 63) 394 nm (sh), 422 nm (ε = 66).

Decomposition of *N*-benzyl-*N*-nitrosopivalamide

The seals to the solvent containers, benzene-d_6, toluene-d_8, and mesitylene-d_{12}, were opened in the glove box. The solvent was then dried over sodium sulfate for 30 minutes in order to remove trace moisture. 1.5 ml of the appropriate solvent was then pipetted into 5 ml pressure vials. 100 μL of NBNP were pipetted into the pressure vials and allowed to decompose at 21 °C for 48 h (10 half-lives). A sample of the NBNP was analyzed *via* FT-NMR in order to establish a baseline percent decomposition, which was used to correct the percent solvent derived product and percent ion collapse product. All decompositions were performed in triplicate.

N-Benzyl-*O*-benzoylhydroxylamine (7)

This was prepared by the method of Zinner.[16d] IR (CH_3Cl) 1725 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.28 (s, 2H), 7.29–7.97 (m, 9H), 7.98 (d, 2H, J = 12 Hz).

Decomposition of *N*-benzyl-*O*-benzoylhydroxylamine (7)

This was performed as outlined in Ref. 3*c*.

Analysis of decompositions

The percent solvent derived products (SDPs) and percent ion collapse products (ICPs) were determined using ^1H NMR spectroscopy by integrating the benzylic signals of starting materials and of the products. The values given for % SDP and % ICP are averages of a least three replicants, and three sets of integration values per run.

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8 (*a*) Extensive work on carbenium ion lifetime and solvent and/or nucleophile interaction have shown that in the presence of very strong nucleophiles such as azide, combination with carbenium ions are diffusion controlled.[8b–e] With poorer nucleophiles the rates of reaction depend upon the reactivities of both cation and nucleophile as well as carbocation lifetime and occur at rates much lower than diffusion.[8b–e] In contrast, carbocations generated *via* nitrosoamide decomposition do not react with saturated solutions of nucleophiles (including azide).[3g] In these cases, the carbocation enters into reaction with solvent at a rate significantly larger than diffusional encounter with nucleophilic solute.[3g] In deamination the boundary conditions on product formation are the very short carbocation lifetime, the statistical distribution of nucleophiles (solute and solvent) external to the and the cage effect.[3g]; (*b*) J. P. Richard, *Tetrahedron*, 1995, **51**, 1535; (*c*) R. A. McClelland, C. Chan, F. Cozens, A. Modro and S. Steenken, *Angew. Chem., Int. Ed. Engl.*, 1991, **30**, 1337; (*d*) J. P. Pezacki, D. Shukla, J. Lusztyk and J. Warkentin, *J. Am. Chem. Soc.*, 1999, **121**, 6589; (*e*) T. L. Amyes and J. P. Richard, *J. Am. Chem. Soc.*, 1990, **112**, 9507.

9 (*a*) For example, the deaminatively-generated benzyl cation is without action on methylene chloride but the 1-norbornyl cation generated *via* deamination abstracts chloride from CH_2Cl_2[9b]; (*b*) E. H. White, R. H. McGirk, C. A. Aufdermarsh, Jr., H. P. Tiwari and M. J. Todd, *J. Am. Chem. Soc.*, 1973, **95**, 8107; (*c*) It is unclear whether the greater volume or lower volatility of N_2O *vs.* N_2 is the major operating factor. Indeed, other factors such as the polarity, polarizability, *etc.* may also be important. For example, diffusion of the polar N_2O through the non- polar "skin" of the solvent cage (in a non-polar solvent) may be less facile than the similar departure of N_2; (*d*) The physical shielding of the cation from the nascent counterion probably possesses a spatial component in that the multiple NEs keep the ions at an enhanced distance apart from each other. Since it would presumably take a longer time for the multiple NEs to diffuse from the inter-ion space, then the shielding possesses a time-based component as well.

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11 R. W. Darbeau, G. A. Trahan, L. M. Siso, N. Alvarez, in preparation.

12 (*a*) An alternative name for this compound is benzyl *N*-hydroxy-carbamate; (*b*) Early quenching with $NaHCO_{3(aq)}$ was employed to circumvent acid-catalyzed dealkylations, and disproportionations; (*c*) The δ values of **4** and **5** in benzene, toluene, and mesitylene are 4.90, 5.06, 4.79, and 4.31, 4.48, 4.81, respectively.

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14 (*a*) Similar to the dediazoniation step in the Wolff–Kishner reduction when the diazenide ion fragments to the alkanide ($RCH_2N{=}N^- \longrightarrow RCH_2^- + N_2$); (*b*) Let k_+ = rate of cationic decarboxylation (to **3c**) and k_- = rate of anionic decarboxylation (to **3d**). If $k_+ \gg k_-$, then negligible product from **3d** would arise. If $k_+ \ll k_-$, then negligible product from **3c** would be expected. Since products from both **3c** and **3d** are observed then the $k_+ \approx k_-$; because more **3c**-derived product is observed, k_+must be somewhat larger than k_-.

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