A Study of Essentially Free Carbocations Derived via Diazonium and Oxo Diazonium Ions in the Liquid Phase

Ron W. Darbeau,* Emil H. White, Fenhong Song, Nyla R. Darbeau, and James Chou

Departments of Chemistry, McNeese State University, Lake Charles, Louisiana 70609, and The Johns Hopkins University, Baltimore, Maryland 21218

Received March 22, 1999

Nitrogen- and nitrous oxide-separated ion pairs containing 4-substituted benzyl cations and carboxylate or tosylate anions were prepared by thermolysis of *N*-nitroso- and *N*-nitroamides, acidification of phenyldiazomethane, and nitrosation of *N*-benzyl-*O*-benzoylhydroxylamine. The cations were generated in benzene/toluene and benzene/anisole mixtures and were found to partition between the counterion and the solvent and between the aromatic cosolvent and benzene. A familial relationship among the methods was observed. As the cation became more reactive, the yield of solvent-derived products (SDPs) rose and the ratio of rate constants for its reaction with toluene versus benzene, k_T/k_B, fell. The yield of SDP also rose as the temperature was decreased and as N_2 was replaced by N_2O; however, k_T/k_B remained unchanged. Inert diluents had no effect on k_T/k_B but decreased hydrocarbon yield by 40% on 2-fold dilution. In the presence of reactive diluents that are converted into secondary alkylating agents, both the % hydrocarbon and k_T/k_B rose. These results are interpreted in terms of the intermediacy of inert-molecule-separated ion pairs (IMSIPs) in deamination. The cation reacted with benzoates and tosylates not only at the oxygens but also at the *ipso* carbon; subsequent decarboxylation and desulfonylation, respectively, led to diphenylmethanes. The ester/SDP ratio is introduced as a new measure of carbocation reactivity.

Introduction

We describe here newly discovered aspects of the chemistry of deaminatively generated carbocations that are formed as part of an inert-molecule-separated ion pair (IMSIP). Several methods[1−6] for the generation of such carbocations have been developed leading to highly reactive cations inaccessible via solvolytic routes. The oldest method of deamination, the reaction of amines with aqueous solutions of nitrous acid,[7] is the least useful method because of the plethora of products formed and the aqueous insolubility of many amines with high molecular masses. Related methods have utilized amine−alkyl nitrite reactions in reactive solvents as well as the reaction of other nitrosating agents e.g. dinitrogen tetroxide (N_2O_4),[9] nitrosyl halides (NOX),[10] and nitrosonium salts (e.g. NO^+ BF_4^-) with isocyanates and sulfinylamines.[11] Ion pairs containing alkyl diazonium ions can also be made by the acidification of diazoalkanes but the element of chirality at the reaction center is unavailable by this approach.

White[12a] and others[13] have developed intramolecular modes of deamination by appropriate modification of the amine or by attaching it directly to a nitrous acid equivalent. Thus, the generation of carbocations from *N*-nitroso- and N-nitroamides, e.g., are unimolecular processes (reactions **I** and **III**, Scheme 1).[13] In these cases the substrates already possess built-in groups so that on thermolysis diazonium ions (or analogues) are formed; the latter then dediazoniate to the corresponding carbocation(s) (reactions **I** and **III**).

Selected Precursors to Diazonium and Oxo Diazonium Ions. In the present study, reactions **I**−**IV** were employed. In reaction **I**, an N-alkyl-*N*-nitrosoamide, **1**, rearranges on heating to form an unstable *trans*-diazotate ester, **2**, which then fragments into an intimate ion pair, **3**, containing a diazonium ion. The latter readily dediazoniates to form a nitrogen-separated ion pair, **4**. The carbocation in **4** can react with nucleophiles, e.g., the solvent and the counterion. The solvent can capture the cation if the former possesses π- and/or n-electrons. Scavenging of the cation by the counterion can occur only after the inert molecule (IM) diffuses sufficiently out of the pocket between the ions. The cations undergo a variety of motions including rotations so that a significant

* Address correspondence to this author at McNeese State University.

(1) Baumgarten, R. J.; Curtis, V. A. *Chemistry of Amino, Nitroso and Nitro Compounds*; Patai, S., Ed., Wiley: New York, 1982; Vol. 2, pp 929−97.

(2) (a) Moss, R. A. *Acc. Chem. Res.* **1974**, *7*, 421. (b) Moss, R. A. *Chem. Eng. News* **1971**, *Nov. 22*, 28.

(3) Huisgen, R.; Reinertshofer, J. *Justus Liebigs Ann. Chem.* **1952,** *575*, 197.

(4) Huisgen, R.; Reimlinger, H. *Justus Liebigs Ann. Chem.* **1956**, *599*, 161.

(5) White, E. H.; Lim, H. M. *J. Org. Chem.* **1987**, *52*, 2162−2166.

(6) White, E. H.; McGirk, R. H.; Aufdermarsh, C. A., Jr.; Tiwari, H. P.; Todd, M. J. *J. Am. Chem. Soc.* **1973**, *95*, 8107−8113.

(7) Muller, H.; Hais, H. *Chem, Ber.* **1963**, *96*, 570.

(8) (a) Jurewicz, A. T.; Bayless, J. H.; Friedman, L. *J. Am. Chem. Soc.* **1965**, *87*, 5788. (b) Olah, G. A.; Friedman, N.; Bollinger, J. M.; Lukas, J. *J. Am. Chem. Soc.* **1966**, *88*, 5328.

(9) Schmid, H.; Sami, A. F. *Monatsh. Chem.* **1955**, *86*, 904.

(10) Soll, H. *Methoden der Organischen Chemie*; Muller, E., Ed.; Houben-Weyl; Georg Thieme Verlag: Stuttgart, Germany, 1958; Vol. 11, Part 2, p 133.

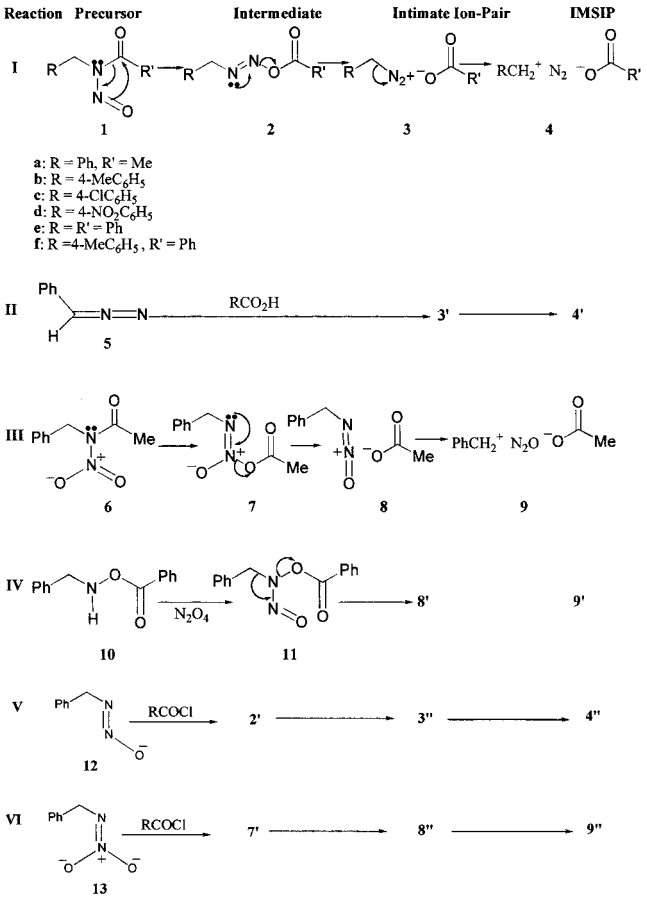
(11) Olah, G. A.; Overchuck, N. A.; Lapierre, J. C. *J. Am. Chem. Soc.* **1965**, *87*, 5785.

(12) (a) White, E. H.; Woodcock, D. J. *The Chemistry of the Amino Group*; Patai, S., Ed.; Wiley-Interscience: New York, 1968; pp 440−483. (b) Keating, J. T.; Skell, P. S. *Carbonium Ions*; Olah, G. A., Schleyer, P. v. R., Eds.; Wiley-Interscience: New York, 1970; Vol. 2, pp 573−653. (c) Friedman, L. *Carbonium Ions*; Olah, G. A., Schleyer, P. v. R., Eds.; Wiley-Interscience: New York, 1970; Vol. 2, pp 655−713. (d) Kirmse, W. *Angew. Chem.* **1976**, *88*, 273. (e) Moss, R. A. *Acc. Chem. Res.* **1974**, *7*, 421.

(13) (a) Huisgen, R.; Ruchardt, C. *Justus Liebigs Ann. Chem.* **1956**, *601*, 1. (b) White, E. H.; Dolak, L. A. *J. Am. Chem. Soc.* **1966**, *88*, 3790.

10.1021/jo990494m CCC: $18.00
Published on Web 07/23/1999

Scheme 1. Precursors of Benzyl Cations via Deamination



amount of inverted ester and racemized solvent-derived products (SDPs) can be observed depending on the structure of the carbocation.[15c]

Diazoalkanes (e.g., **5**) on general-acid protonation appear to lead directly to the intimate ion pair, **3** (reaction **II**),[14] and eventually the same suite of particles in the IMSIP as were formed in the thermolysis of **1**. *N*-Alkyl-*N*-nitroamides, **6**, are, like their nitroso analogues, thermolabile[15g] and rearrange on heating via diazoxy esters, **7**, to form a nitrous oxide-separated ion pair, **9** (reaction **III**). An analogue of **9** arises from the labile *N*-alkyl-*N*-nitroso-*O*-benzoylhydroxylamine, **11**, formed by nitrosation of the *N*-alkyl-*O*-benzoyl precursor, **10** (reaction **IV**). Alternative routes to **4** and **9** exist, among them are the acylations of *anti*-diazotates, **12** (reaction **V**), and salts of nitroamines, **13** (reaction **VI**), respectively.

The intermediates shown for reactions **I** and **III**−**VI** are too thermolabile to be detected even at −80 °C by IR and NMR spectroscopy.[6,16c] The subsequent fragmentations of these intermediates to yield diazonium ions (or analogues) then carbocations and finally esters are very fast.[15c] This celerity was demonstrated by White et al.[15c] who showed that a carbonyl-labeled, optically active N-α-phenylethyl nitrosoamide afforded ester with 81% retention of configuration which retained 69% of the label in the carbonyl group.[15c] Moreover, the ^{18}O-distribution was essentially the same in the 19% of the inverted ester that had formed.[15c] Therefore, the intermediate carbocation−carboxylate ion pair is too short-lived to allow either the carboxylate oxygens to equilibrate (in protic solvents) or to allow the cation to rotate sufficiently to lead to racemic ester on internal return.

Inert-Molecule Separated Ion Pairs in Solvolysis and the Reactivity of Deaminatively Formed Carbocations. Carbocations generally are formed from the heterolysis of some weak, polar bond in polar solvents in which the departure of a good leaving group and the formation of a resonance and/or inductively stabilized cation are involved. Ion pairs can be generated readily in polar solvents, with a subsequent step involving the formation of a solvent-separated ion pair. In the nitrosoamide decomposition (reaction **I**) a third, inert body is generated directly between the gegenions and this IMSIP[17] essentially determines the subsequent chemistry.

Deaminatively formed carbocations are more reactive than their solvolytic analogues. For example, the nitrous acid deamination of 1-propylamine in acetic acid yields 1-propyl acetate and 2-propyl acetate in 60% and 40% yields, respectively.[13] The solvolysis of 1-propyl tosylate in acetic acid, however, yields 97% of the 1-propyl acetate and only 3% of the 2-propyl ester.[13] This result, in addition to the low yield of norbornyl ester in deamination of *N*-1-norbornyl-*N*-nitrosonaphthamide generated in situ in methylene chloride,[6] and the absence of both ^{18}O-scrambling and racemization of the stereocenter in the decomposition of optically active, carbonyl-labeled *N*-α-phenylethyl nitrosoamide[15c] form the basis of the nitrogen-separated ion-pair model.[15c]

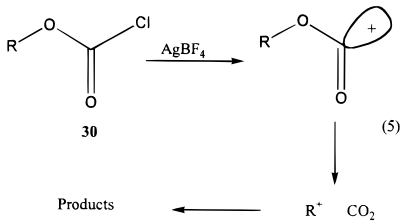
Using the deaminative approach (especially reactions **I**, **III**, and **IV**), it is possible to generate carbocations in

(14) More O'Ferrall, R. A.; Kwok, W. K.; Miller, S. I. *J. Am. Chem. Soc.* **1964**, *86*, 5553.

(15) (a) White, E. H.; De Pinto, J. T.; Polito, A. J.; Bauer, I.; Roswell, D. F. *J. Am. Chem. Soc.* **1988**, *110*, 3708−3709. (b) *N*-Benzylacetonitrilium triflate is stable when dry,[15a] but in the presence of water or a more nucleophilic counterion (e.g., pivalate) it yields the acetamide[15a,16c,30b] and the diacylbenzylamine, respectively.[16c,30b] (c) White, E. H.; Field, K. W.; Hendrickson, W. H.; Dzadzic, P.; Roswell, D. F.; Paik, S.; Muller, P. W. *J. Am. Chem. Soc.* **1992**, *114*, 8023−8031. (d) White, E. H.; Roswell, D. F.; Politzer, I. R.; Branchini, B. R. *J. Am. Chem. Soc.* **1975**, *97*, 2290−2291. (e) White, E. H.; Roswell, D. F.; Politzer, I. R.; Branchini, B. R. *Methods Enzymol.* **1977**, *46*, 216. (f) White, E. H.; Jelinski, L. W.; Perks, H. M.; Burrows, E. P.; Roswell, D. F. *J. Am. Chem. Soc.* **1977**, *99*, 3171. (g) N-Nitrosoamides are somewhat more thermolabile than the corresponding N-nitroamide. For example, *N*-benzyl-*N*-nitrosoacetamide (**1a**) has a half-life of ∼45 min at 80 °C but its *N*-nitro analogue (**6**) has a $t_{1/2}$ of ∼3 h under the same conditions.[16c]

(16) (a) White, E. H.; Darbeau, R. W.; Chen, Y.; Chen, D.; Chen, S. *J. Org. Chem.* **1996**, *61*, 7986. (b) Darbeau, R. W.; White, E. H. *J. Org. Chem.* **1997**, *62*, 8091. (c) Darbeau, R. W. Ph.D. Thesis, The Johns Hopkins University, Baltimore, MD, 1996. (d) This approach is useful in the direct monoalkylation of π-rich heteroaromatics in good to excellent yields.[16b] (e) White, E. H. *Tetrahedron Lett.* **1997**, *38* (44), 7649.

(17) (a) Nitrogen and nitrous oxide are not the only gases that can be generated between a pair of gegenions. For example, treatment of alkyl chloroformates (**30**) with silver salts (eq 5)[17b]



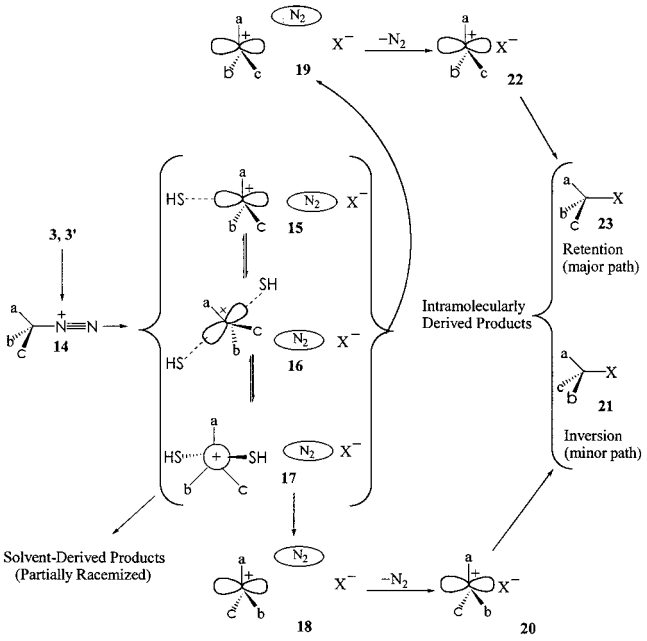
results in the facile generation of a carbon dioxide separated ion pair.[17b] This method is analogous to the deaminative approach but is less useful because it is limited to nonnucleophilic media, it is heterogeneous, and more side reactions occur.[17b] Deaminations via *N*-nitro- and *N*-nitrosoamides circumvent these drawbacks and are more useful for the clean generation of IMSIPs. (b) Beak, P.; Trancik, R. J.; Simpson, D. A. *J. Am. Chem. Soc.* **1969**, *91*, 1, 5073.

nonpolar solvents such as benzene[8,16c] and cyclohexane.[16c] Specific solvation of the carbocations appears to be unnecessary presumably because of the low activation energy for dediazoniation (loss of nitrogen or nitrous oxide). This low activation energy allows the resultant carbocation to be formed with minimal solvent participation and maximal positive charge on the electron-deficient center.[15c] Additionally, the temporary screening of the cation from the counterion by the physical presence of the IM results in the existence of an essentially free cation. The carbocations formed by this approach are extraordinarily reactive,[6,12a,15,18] and they probably represent as free a carbocation as can be generated in liquid media.[16a] The counterion and the substrate compete for the carbocation in irreversible reactions,[6,15c] and the high speed of the counterion reaction to yield ester, limited by the rate of diffusion of the IM into the medium, results in the carbocation having an exceedingly short time to react with the solvent before being scavenged by the counterion.[15c] The IM (=nitrogen, nitrous oxide), by virtue of its physical separation of the ions for a finite period of time, plays a pivotal role with respect to competing reaction modes allowing a carbocation−solvent interaction to not only compete but potentially to dominate the reaction.[6,16b,c]

Thus even though solvent interaction is unnecessary, SDPs can predominate in the product mixture even in the presence of a counterion of good nucleophilicity.[6,16b] This occurrence requires the solvent reactivity to be at some threshold level and matched to the reactivity of the cation. For example, the major product from the partitioning of deaminatively generated 1-norbornyl cation between its temporarily shielded counterion (naphthoate) and the neutral and relatively inert solvent, methylene chloride, is 1-norbornyl chloride. Ostensibly, it arises via reaction of the carbocation with solvent followed by an S_N2 reaction on the chloronium ion by the counterion;[6] the minor product is the corresponding ester, norbornyl naphthoate.[6] Even the resonance-stabilized benzyl cation exhibits high reactivity as it partitions 1:4 between its counterion (benzoate) and pyrrole.[16b] It also benzylates ethers,[15a] acetonitrile,[15a,16b,c] and benzene[16a,c] in fair to good yield.

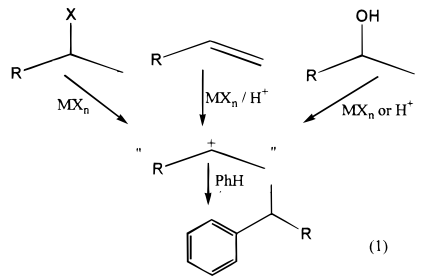
Ostensibly, the IMSIPs, **15**−**19** (Scheme 2), generated by fission of the C−N bond of the antecedent diazonium ion **14** differ principally in the orientation of the carbocation relative to the counterion and in the position of the inert molecule. Many of the carbocations in orientation **15** are captured by the counterion after diffusion of the nitrogen (to form **19**). A significant fraction of the cations reach orientations such as **16** and **17** by rotations, along what is represented (Scheme 2) as their *z*- and *y*-axes, respectively. Here strong π, p-electron donation from solvent molecules may occur to the electron-deficient centers. Consequently, predominant (if not exclusive) capture of these cations by the solvent occurs.[6,15a,c] Racemized SDPs may form from **16** and **17**, while **18** can account for the observation of inverted ester (Scheme 2).[15c]

Scheme 2. Reaction Pathways of Alkanediazonium Ions[15c]



Advantages of Generating Carbocations by the Nitrosoamide Approach. The unimolecular nitrosoamide decomposition[13] (reaction **I**) introduces nitrogen-separated carbocation−counterion ion pairs[6,12a,15] into solvents[18a] ranging from carboxylic acids[13] through alcohols[19] to hydrocarbons (e.g., cyclohexane[16c] or benzene[8,16c]). Nitrosamides are easily prepared and can be cleanly decomposed[16c] at a wide range of temperatures (−20 to ∼100° C).[18b,c] Excellent product balance is observed, and the products (in most cases >99%) have been identified and quantitated. No catalysts are used and isomerizations of the products do not occur; the alkylation is under strict kinetic control.[16b,c] The nitrosamide system thus allows external factors such as temperature, polarity, viscosity and dilution etc., to be studied readily.[16c]

Friedel−Crafts Alkylation. The Friedel−Crafts (F−C) alkylation reaction is widely used, it is synthetically important, and its mechanism continues to be the subject of lively debate.[16a,20,21] In the standard F−C alkylation a Brønsted or Lewis acid catalyzes the reaction of aromatic compounds with alkyl esters of strong acids, with alcohols, or with unsaturated compounds (eq 1). The benzylation of benzene−toluene mixtures, in particular, has been studied extensively.[20,21] The alkylation of aromatic compounds using the nitrosoamide approach represents



(18) (a) Nitrosoamides are highly soluble in solvents ranging from cyclohexane (see text) to carboxylic acids.[13] (b) The thermal stability of *N*-nitrosamides decreases as the steric bulk of the alkyl and acyl groups flanking the *N*-nitroso moiety rises. Half-lives of *N*-benzyl-*N*-nitrosotriflamide and *N*-benzyl-*N*-nitrosopivalamide are ∼15 and 30 min, respectively, at 25 °C in $CDCl_3$, while that of *N*-benzyl-*N*-nitrosoacetamide is ∼45 days under the same conditions. (c) White, E. H.; Stuber, J. E. *J. Am. Chem. Soc.* **1963**, *85*, 2168.

(19) White, E. H.; Field, K. W. *J. Am. Chem. Soc.* **1975**, *97*, 2148−2153.

Table 1. Product Distributions in *N*-Nitrosamide-Mediated Benzylations of Equimolar Benzene and Toluene[a−c]

			yields (%)			isomer distribution (%) (4-R-benzyltoluenes)		
nitrosamide	R	temp (°C)	ester	SDP[d]	k_T/k_B[e]	*ortho*	*meta*	*para*
1a	H	80	91.5	8.5	2.51	43.8	17.8	38.4
1b	Me	80	98.0	2.0	4.39	44.1	14.1	41.8
1c	Cl	80	90.7	9.3	2.41	44.0	18.3	37.7
1d	NO_2	80	73.4	26.6	1.33	45.1	26.4	28.5
1e		80	93.4	6.6	2.46	44.3	17.8	37.9
1e		40	89.4	10.6	2.55	46.0	19.4	34.6
1e		25	87.2	12.8	2.66	46.6	18.6	34.8

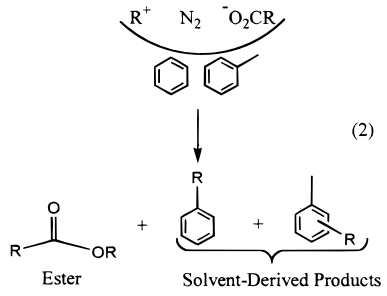
[a] Product distributions by NMR and GC (30 m SE−30, 0.25 mm i.d.; column temperature = 145 °C); total yields of products ∼97%. [b] [**1**] ∼0.05 M; pyridine (∼0.01 M) present in all runs. [c] Maximum standard deviations for $k_T/k_B = 0.10$; for relative yields = 0.48. [d] Solvent-derived products. [e] Values independent of solvent ratio.

an alternative route to alkylarenes relative to the standard F−C approach.[16d]

We report here a study of the benzylation of benzene−toluene and benzene−anisole mixtures using 4-R-benzyl electrophiles (R = Me, H, Cl, NO_2) generated principally by the thermolysis of nitrosoamides.

Results and Discussion

Benzylation of Benzene/Toluene Mixtures. Nitrosoamides **1a**−**e** were decomposed in equimolar mixtures of benzene and toluene in the presence of 2 equiv of pyridine.[22b] The latter was added to neutralize any acid that formed during the reaction and to inhibit the formation of certain impurities (vide infra). A simple, reproducible product distribution was observed (Table 1), in which the ester and the diphenylmethanes were the major (∼98%) products[22a] (eq 2). The yield of SDPs varied



from 2% for the 4-methylbenzyl nitrosoamide (**1b**) to 26.6% for the 4-nitrobenzyl nitrosoamide (**1d**) (Table 1). The high reactivity of the carbocations is apparent when the k_T/k_B and the % *meta* isomer from the standard and from the nitrosoamide Friedel−Crafts benzylations of benzene−toluene mixtures are compared.[16a,c] The nitrosoamide approach yields values of $k_T/k_B \sim 2.5$ and % *meta* isomer ∼ 18% for the parent benzyl cation (from **1a**) while the standard F−C approach from the reaction of benzyl chloride with $AlCl_3$ yields $k_T/k_B \sim 2.5-20$[21] and % *meta* isomer ∼ 4.0−6.3%[21] for the corresponding benzyl electrophile.[16a,21]

Table 2. Product Yields[a] from Deaminative Benzylation of Benzene and Toluene[b]

		% yield[c]		
source of cation	temp (°C)	ester	DPM + 4-R-DPM	k_T/k_B[d]
1a	80	91.5	8.5	2.51
	40	89.3	10.7	2.41
1e	80	93.4	6.6	2.34
	40	89.4	10.6	2.28
	25	87.2	12.8	2.46
5	25	86.9	13.1	2.51
6	80	88.3	11.7	2.45
10	25	85.0	15.0	2.56
	−78[e]	80.8	19.2	
1b	80	98.0	2.0	4.39
1c	80	90.7	9.3	2.41
1d	80	73.4	26.6	1.33
24	80	82.9	17.1	2.66
	40	79.0	21.0	2.40
	25	77.3	22.7	2.50

[a] Standard deviation for ester/SDP data ∼0.7; for k_T/k_B data, standard deviation ∼ 0.08. [b] Equimolar benzene−toluene. [c] Determined by NMR spectroscopy. [d] Average value from NMR and GC analyses. [e] Run performed in toluene-d_8 and the yield of hydrocarbons corrected to equimolar benzene−toluene by dividing the observed yield by 1.45 (derived from the average k_T/k_B value) giving cited value.

Table 2 shows the product distribution from thermolysis of *N*-nitroso- and *N*-nitroamides (**1a**−**e** and **6**, respectively), nitrosation of *N*-alkyl-*O*-benzoylhydroxylamine (**10**), and acidification of phenyldiazomethane (**5**). For

(20) (a) Olah, G. A., Ed. *Friedel−Crafts and Related Reactions*; Wiley: New York, 1963; Vols. 1−4. (b) Lowry, T. H.; Richardson, K. S. *Mechanism and Theory in Organic Chemistry*, 2nd ed.; Harper and Row: New York, 1987; p 626. (c) Marsh, J. *Advanced Organic Chemistry*, 4th ed., John Wiley and Sons: New York, 1992; Chapter 11.

(21) (a) Olah, G. A.; Kuhn, S. J.; Flood, S. H. *J. Am. Chem. Soc.* **1962**, *84*, 1688. (b) Olah, G. A.; Overchuck, N. A. *J. Am. Chem. Soc.* **1965**, *87*, 5786. (c) Olah, G. A.; Kobayashi, S.; Tashiro, M. *J. Am. Chem. Soc.* **1972**, *94*, 7448. (d) De Haan, F. P.; Chan, W. H.; Chen, W. D.; Ferrara, D. M.; Giggy, C. L.; Pinkerton, M. J. *J. Org. Chem.* **1989**, *54*, 1206. (e) De Haan, F. P.; Covey, W. D.; Ezelle, R. L.; Margetan, J. E.; Pace, S. A.; Sollenberger, M. J.; Wolf, D. S. *J. Org. Chem.* **1984**, *49*, 3954. (f) Olah, G. A.; Olah, J. A. *J. Org. Chem.* **1967**, *32*, 1612.

(22) (a) A feature common to thermolyses of many nitrosoamides is denitrosation in which the nitroso group is replaced by a proton. In thermolyses of the nitrosotosylamide (**24**), denitrosation accounts for 25% of the products in the absence of base but only ∼5% in the presence of 2,6-di-*tert*-butyl-4-methylpyridine.[16c] This result indicates that the reaction is acid-catalyzed. In thermolyses of nitrosocarboxamides denitrosation accounts for only 1−2% of the product in the presence of base. With sterically hindered nitrosocarboxamides such as those derived from dimethyl- and trimethylacetamides, no denitrosation occurs.[16c] Thus the extent of denitrosation depends, at least in part, on the acid moiety in the starting nitrosoamide. The stronger the acid in the catalytic step, the larger is the degree of denitrosation. (b) The deaminations of nitroso- and nitrocarboxamides (**1** and **6**, respectively), the nitrosotoluenesulfonamide (**24**), phenyldiazomethane (**5**), and *N*-benzyl-*O*-benzoylhydroxylamine (**10**) were performed in the presence of 2 equiv of pyridine (or 2,6-di-*tert*-butyl-4-methylpyridine in the case of **24**). This nonnucleophilic base was used partly to neutralize any acid that was produced during the reaction and also to inhibit the formation of an unknown impurity which compromised the k_T/k_B and isomer distribution data by eluting in the "valley" between the *meta* and *ortho* isomers during GC analyses. Benzyl azine, the stilbenes, and diphenylethane were ruled out as the impurity. The *C*-benzylpyridines were not detected (to the detection limit ∼0.01%) by ^{1}H NMR (absence of signals at δ 3.78−4.14 in $CDCl_3$);[24c] nor was *N*- benzylpyridine observed (absence of signal at δ 6.4 in $CDCl_3$).[24d] The absence of benzylpyridines is consistent with the low mole fraction of pyridine in the medium.

Table 3. Effect of the Inert Molecule on the Yield of Hydrocarbon

species	reacn	counterion	inert molecule	temp (°C)	% HC[a]	% diff $SDP_{N_2O} - SDP_{N_2}$
1a	thermolysis	acetate	N_2	80	8.5	38
6			N_2O	80	11.7	
1e		benzoate	N_2	25	13.1	
5	acidification		N_2	25	12.8	
av			N_2	25	13.0	16
10	nitrosation		N_2O	25	15.0	

[a] HC = hydrocarbon.

these four methods the k_T/k_B values and the isomer distribution are the same, within experimental error (Table 2). This result suggests that an intrinsic familial relationship exists among these deaminative approaches.[23]

The k_T/k_B values and the relative yields of ester and SDPs were measured as a function of changes in the counterion, the temperature, the IM, the precursor, and the concentration of aromatic substrate in the medium. The results are shown in Tables 1−4, and the data are discussed in terms of each variable.

Effect of Cation Reactivity on Product Distribution. As the R-group is varied from Me to NO_2 the stability of the 4-R-benzyl cation decreases. The data (Table 1) show that for the series 4-Me to 4-NO_2, the yield of SDPs rises from 2% to 26.6%, respectively. This result indicates that as the reactivity of the cation rises, its vulnerability to interception by the solvent (before the diffusion of nitrogen exposes the counterion) also increases. The data (Table 1) further show that for the series 4-Me to 4-NO_2 the k_T/k_B decreases (4.39 to 1.33). This result and the increasing yield of SDP (vide supra) indicate that as the cation becomes more reactive, it becomes less selective in its reactions.[16a,c]

Effect of the Counterion on Product Distribution. The percentage of hydrocarbon increased from 12.8 when the parent nitrosobenzamide (**1e**) was decomposed in benzene−toluene at 25 °C to 22.7 when the nitrosotosylamide (**24**) was the source of the benzyl cation at the same temperature (Table 2). This 77% rise in the yield of hydrocarbon is likely due to the higher nucleophilicity of benzoate ($n = 2.8$)[24a] vs tosylate ($n \sim 0.5$)[24a] which allows the former to be more efficient at scavenging the cation than the latter. As the nucleophilicity of the counterion is decreased from acetate ($n = 2.7$)[24a] to tosylate ($n \sim 0.5$),[24a] the k_T/k_B value barely changes from 2.51 to 2.66 at 80 °C (Table 2). It would appear then that changes in the counterion have little or no effect on the k_T/k_B value. This insensitivity of k_T/k_B to the counterion presumably arises partly because the cation is screened from the counterion by the nitrogen (or nitrous oxide) molecule during the carbocation−solvent interaction. Consequently, the nature of the counterion would be expected to have little effect on the cation−solvent reactions as observed. The near constancy of k_T/k_B may also be due to the similarity in the k_T and k_B terms (i.e. the low $\Delta\Delta G^{\ddagger}$ between the cation−toluene and the cation−benzene reactions). This low $\Delta\Delta G^{\ddagger}$ value is believed to be responsible for the general insensitivity of the k_T/k_B to changes in other factors such as the identity of the inert molecule, the temperature, etc. (vide infra).

It should be noted that the ratio of the yields of SDP at 80 °C from decomposition of **24** (17.1%; Table 2) to that from decomposition of **1a** (8.5%, Table 2) is ∼2. However, the ratio of the nucleophilicity parameters (*n* values)[24a] is ∼6 suggesting that the ratio of rate constants for acetate/electrophile reaction vs that for tosylate/electrophile reaction is $\sim 10^6$.[24a] The small change in % SDP (Table 2) despite the large change in the nucleophilicity of the counterion is consistent with screening of the counterion from the cation during its reaction with the aromatic substrate (eq 2).

Influence of the Inert Molecule. The decompositions of **1a** and **6** differ principally in the identity of the IM (N_2 and N_2O, respectively) which separates the benzyl cation from acetate in the first-formed IMSIP (**4** vs **9**). The relative yield of hydrocarbons from these decompositions rises from 8.5% for **1a** to 11.7% for **6** (Tables 2 and 3).

Decomposition of **1e** and the acidification of **5** both produce N_2-separated benzyl cation−benzoate ion ion pairs (**4**, **4′**). The yields of SDP from these reactions are essentially the same at 12.8% and 13.1%, respectively (Tables 2, 3). In contrast, nitrosation of **10** produces benzyl cation−benzoate ion ion pairs analogous to **4** and **4′** except that N_2O has replaced N_2 (**9′**). The relative yield of SDP from **10** is 15% (Tables 2 and 3). These data show that as the IM is changed from N_2 to N_2O, the relative yield of SDP rises.

The increased yield of SDP as the IM is varied from N_2 to N_2O is likely a result of differences in molecular weight and molecular volume of the two gases. N_2O is 57% heavier and 17% larger than N_2.[25] It is likely that the heavier N_2O would diffuse more slowly than N_2 from between the counterions, and by virtue of its larger

(23) It has been suggested from a comparison of the decomposition of the 4-octyl analogues of the nitrosoamide **1a** and the diazoalkane **5** in acetic acid that the diazoalkane approach produces a larger relative yield of esters than the nitrosoamide route. However, this conclusion must be treated with reserve because (1) the diazooctane route led to low product recoveries (29.5%), relative to the nitrosoamide yield reported (87.8%), (2) information on the purity of the diazoalkane was not provided, and (3) details of the techniques used to introduce the diazoalkane into the acetic acid were not given (high local concentrations of the diazoalkane could lead to side reactions): Southam, R. M.; Whiting, M. C. *J. Chem. Soc., Perkin 2*, **1982**, 597−603.

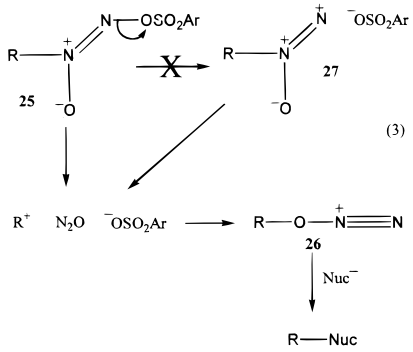
(24) (a) The nucleophilicity, *n*, of a reagent is defined within the linear free energy relationship "$\log(k/k_o) = sn$", where *k* is the rate constant for the S_N2 reaction of a substrate (chosen by Swain and Scott to be MeI) with a particular nucleophile at 25 °C; k_o is the corresponding rate constant with a standard nucleophile (chosen by Swain and Scott to be water). The term "*s*" is a parameter which gauges the sensitivity of the substrate toward variation in the nucleophiles: Swain, C. G.; Scott, C. B. *J. Am. Chem. Soc.* **1953**, *75*, 141. (b) Levine, I. A. *Physical Chemistry*, 2nd ed., McGraw-Hill Book Co.: New York, 1983; pp 522−526. (c) Pouchert, C. J. *The Aldrich Library of NMR Spectra*, 2nd ed.; Aldrich Chemical Co. Inc.: Milwaukee, WI, 1983; Vols. I and II. (d) Friedrich, E. C.; Vartanian, P. F. *J. Organomet. Chem.* **1976**, *110*, 159−165.

(25) The molecular diameters (σ) of N_2 and N_2O are 3.681 and 3.879 Å, respectively (Bird, R. B.; Stewart, W. E.; Lightfoot, E. N. *Transport Phenomena*, Wiley: Chichester, U.K., 1960; p 744). The molecular volumes (V_M) were calculated using $V_M = (4/3)\pi r^3$: $V_M(N_2) \sim 26.1$ Å^3; $V_M(N_2O) \sim 30.6$ Å^3. Thus, N_2O is ∼17% larger than N_2.

volume,[25] it would serve as a more effective shield between the cation and its counterion. Consequently, the N_2O-shielded benzyl cation is afforded more opportunity for reaction with the solvent and a larger yield of SDP is observed.

Other differences, e.g., polarity and polarizability, exist between N_2O and N_2, but it is not clear what effect (if any) they have on the partitioning of the benzyl cation between the counterion and the solvent.

A different role for N_2O has been proposed by Maskill et al.,[26] who suggested that the related decomposition of 2-alkyldiazenyl-2-oxide tosylates (**25**) proceeds via a slow, concerted heterolysis into a "very short-lived" N_2O-separated ion pair. This ion pair was proposed to undergo a rapid cation-N_2O recombination, via the oxygen atom of N_2O, to form a "long-lived" oxodiazonium ion (**26**) which is largely responsible for the observed alkylations (eq 3). White previously[15c] has pointed out the unlikeli-



hood of such a reaction on the basis of the probable preference of the first-formed cation for the nucleophilic water and trifluoroethanol in which the reactions were performed rather than for the poorly nucleophilic N_2O.

Since the benzylations involving the N_2-separated ion pair are occurring via the essentially free benzyl cation[1−6,12,15,16] (vide infra), if Maskill's oxodiazonium ion, **26**, was the active electrophile responsible for the benzylations from the N_2O-separated ion pairs, it would be expected that the character of the benzylations would differ markedly between the N_2- and N_2O-separated series. The similarity in both the ester/hydrocarbon (91.5%/8.5% vs 88.3%/11.7%) and k_T/k_B (∼2.7 vs ∼2.5) data in the decompositions of **1a** and **6**, respectively (Table 2), suggests that similar benzylating agents, and hence benzyl cations, are involved in both series.

Additionally, if the benzyloxo diazonium ion were present as a "long-lived" intermediate, it should react with bases with elimination of nitrogen to form benzaldehyde. The latter was not observed (to the detection limit ∼ 0.01%) in the deaminations presented in this work [absence of a singlet at δ 10.3 (^{1}H NMR in benzene−toluene)]. Maskill claimed that the oxo diazonium ion (**26**) was formed in ∼50% of the decompositions[26] but reported the formation of only 1% benzaldehyde.[26] The formation of benzaldehyde from **26** would arise from facile proton and nitrogen losses; the fact that only trace quantities of it were observed is strong evidence against **26** as an abundant, "long-lived" cationic species.

Effect of Initial Geometry. White et al.[15c] examined two extreme aspects of the N_2-separated ion-pair: (1) whether differences in the spatial distributions of the alkyl group relative to the counterion moiety in the initial reaction intermediates **2**, **7**, and **11** and the ion pairs **3** and **8** might be expressed in the product-forming step and (2) whether these initial differences could be averaged out before the final transition states for product formation are reached.

The excellent agreement (∼2% relative error) between the yields of SDPs and k_T/k_B values obtained from the thermolysis of **1e** and the acidification of **5**[23] (Table 2) suggests that the reactions reach a common set of intermediates. It appears, then, that the differences in geometry among the various precursors to the cation, as well as any differences in geometry which may exist immediately after dediazoniation of the diazonium ion, are averaged out prior to the product-forming step. Since the cation−nucleophile reactions are fast,[15c] the processes leading to the randomization of initial geometry must occur rapidly after the formation of the ion pair containing the diazonium ion and/or very rapidly after the diazonium ion dediazoniates. Thermal energy (plus possibly recoil energy) presumably is responsible for erasing any order initially imposed by the structure of the progenitors. This conclusion supports that made previously by White et al.[15c] on the basis of similarities in stereochemical and labeling studies.[15c]

For the decompositions of the *N*-(1-phenylethyl) analogues of **1e** and **11** in dioxane at 25 °C, White et al. reported ester yields of 40 ± 2% and 59 ± 2%, respectively.[15c] However, in their case the pathways available to the cation were elimination (to form styrene) and substitution (to form ester). Proton loss from a carbocation is expected to have a lower activation energy (than reaction with benzene−toluene) and would thus occur earlier when spatial differences might still have been present. The formation of N_2 vs N_2O as the IM (see above) may also have been responsible for the observed differences in product distribution.[15c]

Effect of Temperature on Product Yields. There is a 26% rise in the relative yield of hydrocarbon on lowering the temperature from 80 to 40 °C for the decomposition of **1a** (Table 2). A similar 23% rise is observed over the same range for the decomposition of **24** (Table 2). In the case of **1e**, a 60% increase in the relative hydrocarbon yield is observed from 80 to 40 °C, and the yield almost doubles from 80 to 25 °C for the same series (Table 2). It would appear then that as the reaction temperature is lowered, the yield of SDPs rises.

This behavior is interpreted as being due, at least partially, to the decreasing rate of diffusion of the IM from between the ions as the temperature decreases. This slower diffusion of the IM results in slower exposure of the ions to each other and allows the carbocation more time to react with molecules in the solvent cage before being scavenged by the counterion.

Plots (Figure 1) of the data from the decompositions of **1e** and **24** using ln(% ester) vs reciprocal temperature are linear [R^2 = 0.957 for the parent nitrosobenzamide (**1e**) and R^2 = 0.924 for the nitrosotosylamide (**24**)]. Although these plots are not the usual Arrhenius plots,[24b] they do show a clear temperature dependence of the yield of the ester, indicative of a nonzero activation energy for internal collapse of the gegenions.

Free radical termination is believed to have $E_{act} = 0$.[24b] Because of Coulombic attraction, the internal collapse of an ion pair (to form ester in the present case) would be expected to be even "more" facile than radical combina-

(26) Maskill, H.; Jencks, W. P. *J. Am. Chem. Soc.* **1987**, *109*, 2062.

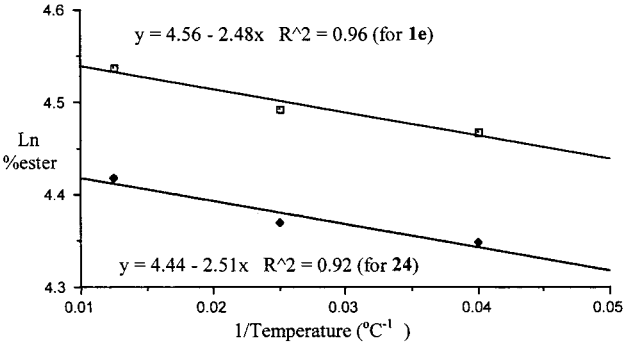


Figure 1. Plot of ln % ester vs 1/*T* for the benzylation of benzene-toluene at 25, 40, and 80 °C using *N*-benzyl-*N*-nitrosobenzamide (**1e**) and *N*-benzyl-*N*-nitrosotosylamide (**24**).

tion where such attraction is absent. That a nonzero activation energy is observed in the present case is indicative of an energy barrier to the recombination of the gegenions, and it is interpreted as arising from the presence of the IM between the ions which sterically hinders ion collapse. This observation and the inference are consistent with the IMSIP model.

In the decomposition of **24**, the ratio "% ester/% SDP" rises by 42% from 25 to 80 °C but only a 6% change in k_T/k_B is observed under the same conditions (Table 2). Thus, while substantial changes in the relative yields of ester and hydrocarbon are observed with changing temperature (Table 2), the k_T/k_B is essentially independent of temperature over the range studied (vide supra).

Effect of Nonreactive Diluents. For reactions involving reactive intermediates, a diluent can exert a statistical effect, it can modify the bulk properties of the solvent, or it can react with the initial intermediate to form secondary intermediates. In the deaminative route, the carbocations are highly reactive and would be expected to react essentially statistically with the nucleophiles in its vicinity. Under these circumstances, yields of the directly formed alkylated aromatic compound(s) are probably a direct function of the mole fraction of the aromatic compound in the solvent.

Twofold dilution by cyclohexane and by pentane causes the % hydrocarbon to fall from 10.6% to 6.8% for the decomposition of the parent nitrosobenzamide (**1e**) at 40 °C (Table 4 and Figure 2). The production of hydrocarbon drops even further to 4.2% when the mole fraction of cyclohexane is raised to 0.75 (Table 4 and Figure 2). These represent a 36% and a 38% drop, respectively. Thus in the presence of nonpolar, inert diluents the yield of hydrocarbon falls by ~37% on 2-fold dilution.

The yield of hydrocarbon from the thermolyses of **1e** falls from 10.6% through 6.8% to 4.2% as the mole fraction of $CDCl_3$ rises from 0 through 0.5 to 0.75 (Table 4, Figure 2). Similarly, the yields of SDP from the decomposition of **1a** fall from 8.5% through 5.4% to 3.6% (Table 4) over the same dilution range with either $CDCl_3$ or cyclohexane as above (Figure 2) (these represent a 36% and a 33% decrease, respectively). Thus, inert diluents regardless of polarity (in the range alkane to $CDCl_3$) bring about the same bulk dilution effect (Table 4).

If the rate of diffusion of N_2 (k_{N_2}) was much lower than the rate of cation−solvent collisions (k_{sol}), then the mole fraction of the inert diluent in the medium would be expected to have no effect on the yield of SDP. Since the diluent exerts a significant effect on the yield of SDP,

Table 4. Effect of Diluents on Product Yields[a] in Deaminative Benzylation of Benzene and Toluene[b]

source of cation	diluent	mole fraction	temp (°C)	% yield[c] ester	% yield[c] DPM + 4-R-DPM	k_T/k_B[d]
		Unreactive Diluent				
1a	none	1.0	80	91.5	8.5	2.45
	$CDCl_3$	0.5		94.6	5.4	2.57
		0.25		96.4	3.6	2.57
1e	none	1.0	40	89.4	10.6	2.28
	$CDCl_3$	0.5		93.2	6.8	2.03
		0.25		95.8	4.2	1.42
		0.125		97.4	2.6	1.23
	C_6D_{12}	0.5		93.2	6.8	2.35
		0.25		95.8	4.2	2.28
		0.125		97.3	2.7	2.20
		Reactive Diluent				
1a	none	1.0	80	91.5	8.5	2.68
	CD_3NO_2	0.36		87.3	12.7	3.38
		0.16		89.7	10.3	3.72

[a] Standard deviation for ester/SDP data ~0.7; for k_T/k_B data, standard deviation ~0.08. [b] Equimolar benzene−toluene was used. [c] Determined by NMR spectroscopy. [d] Average value from NMR and GC analyses.

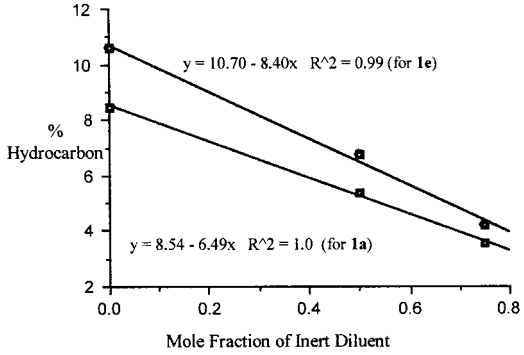


Figure 2. Plot of % hydrocarbon vs mole fraction of inert diluent in the deaminative benzylation of benzene-toluene at 80 °C using *N*-benzyl-*N*-nitrosoacetamide (**1a**) (lower line on graph) and *N*-benzyl-*N*-nitrosobenzamide (**1e**) (upper line on graph). For **1a**, $CDCl_3$ was used as the diluent; for **1e**, $CDCl_3$, pentane, and cyclohexane were used (separately). The data in the latter three cases were identical.

Table 5. Effect of Dilution with $CDCl_3$ on k_T/k_B[a,b] and Isomer Distribution[a] from Decomposition of *N*-Benzyl-*N*-nitrosoacetamide in Benzene−Toluene[c]

mole fraction of $CDCl_3$	temp (°C)	k_T/k_B	isomer distribution % *ortho*	*meta*	*para*
0	80	2.45	43.8	17.8	38.4
0.25		2.57	44.6	16.6	34.8
0.5		2.57	44.5	16.7	34.8

[a] Standard deviation for k_T/k_B data ~0.08; standard deviation for isomer distribution ~0.2. [b] Average value from NMR and GC analyses. [c] Equimolar benzene−toluene was used.

then k_{N_2} and k_{sol} must be similar. Further, since the yield of SDP does not decrease by 50% on 2-fold dilution, then it would appear that not every collision between the cation and diluent leads to ester. It would appear that some carbocations recoiling from fruitless cation−diluent collisions still have the potential to collide with aromatic substrate to produce SDP before the N_2 molecule diffuses sufficiently to expose the counterion.

The data (Tables 4 and 5) for the thermolysis of **1a** also show that dilution with $CDCl_3$ has little or no effect on k_T/k_B. Thus, it would appear that this parameter is

Table 6. Product Distribution[a] from Deaminative Benzylation of Benzene−Toluene Using *N*-benzyl-*N*-nitrosobenzamide at 80 °C as a Function of Mole Ratio of Solvents

mole ratio of benzene:toluene	equiv of Py	yields (%)			isomer distribution		
		ester	SDP's[b,c]	k_T/k_B[c,d]	*ortho*	*meta*	*para*
1:10	2	93.5	6.5	2.50	44.0	18.0	38.0
1:1	2	93.4	6.6	2.46	44.3	17.8	37.9
5:1	2	93.4	6.6	2.46	44.3	17.8	37.9
10:1	2	93.4	6.6	2.48	44.4	17.6	38.0

[a] Yields were measured by NMR and/or by GC; standard deviation ~0.20 for ester−SDP data, ~0.10 for isomer distributions and ~0.10 for k_T/k_B data. [b] SDP = solvent-derived product. [c] Values are normalized to equimolar benzene−toluene. [d] The ratio of the rate constants for benzylation of toluene and benzene.

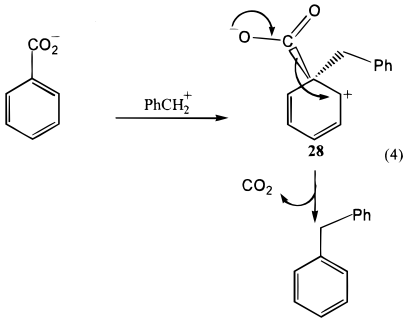
less sensitive than the % ester/% SDP ratio to dilution by inert solvents.

For decompositions of the nitrosoacetamide **1a,** the constancy of the k_T/k_B on dilution (Tables 4 and 5) and as the molar ratio of toluene to benzene was varied (Table 6) indicate that the reactions are competitive. The decreasing k_T/k_B observed on dilutions with inert diluents in the decomposition of *N*-benzyl-*N*-nitrosobenzamide (**1e**) is a result of decarboxylative generation of diphenylmethane and is discussed in the following section.

Carbocation Reaction at the *ipso* Position of the Benzoate and Tosylate Ions. We were surprised to note that when nitrosobenzamide (**1e**) was decomposed in benzene-free $CDCl_3$ and in benzene-free CH_2Cl_2, diphenylmethane (~0.02%) was produced (together with benzyl benzoate). Thermolysis of nitrosobenzamide **1e** in toluene and cyclohexane (both benzene-free) also yielded DPM but to a smaller extent (~0.01%) than in $CDCl_3$. Similarly, nitrosation of the hydroxylamine (**10**) in $CDCl_3$ also generated DPM, as did thermolysis of the nitrosotosylamide (**24**) in the same solvent. Thermolysis of *N*-4-methylbenzyl-*N*-nitrosobenzamide (**1f**) in the absence of benzene yielded 4-MeDPM.

On the other hand, the thermolyses of *N*-benzyl-*N*-nitrosoacetamide (**1a**) and *N*-4-methylbenzyl-*N*-nitrosoacetamide (**1b**) in benzene-free solvents did not produce DPM or 4-MeDPM, respectively. Thus, the unusual formation of DPM and 4-MeDPM occurs in the decomposition of nitrosoaryl amides only.

It appears that the highly reactive benzyl cations generated by deamination are capable of reacting with benzoate (and the *p*-toluenesulfonate groups) not only at the nucleophilic oxygens but also at the aromatic nucleus. Reaction of the benzyl cation at the *ipso* position of the benzoate ion leads to the intermediate **28** (eq 4) which



(4)

undergoes decarboxylative rearomatization to yield the corresponding DPM.

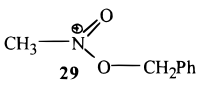
A similar mechanism is proposed for generation of DPMs from tosylates, desulfonylative rearomatization from a species analogous to **28** being the final step. As with decarboxylation, the yield of DPM via this approach is small, ~0.01%. It is interesting that virtually the same yield of DPM is formed from both decarboxylation of benzoates and desulfonylation of tosylates. This observation suggests that the yield of DPM generated by *ipso* reaction is largely determined by the fraction of cations that reach this position.

This *ipso* reaction of benzoates has consequences in the data obtained from thermolysis of **1e** in the presence of $CDCl_3$. Apparently, the amount of DPM from decomposition of **1e**, though small, is larger in more polar media. Thus, as the yield of solvent-generated DPM falls on dilution with $CDCl_3$, the amount of decarboxylatively generated DPM rises to the extent where the value of the ratio of toluene-derived products to DPM (but not the *true* k_T/k_B) begins to fall. This effect leads to unreliable k_T/k_B data when nitrosobenzamide **1e** is decomposed in the presence of $CDCl_3$ as a diluent (Table 4). Because the yield of decarboxylative (and desulfonylative) diphenylmethane is small (~0.02% in $CDCl_3$), it does not significantly affect the ester/hydrocarbon data.

It would be expected that reaction of the cation with the aromatic nucleus of the benzoate ion would also produce the *o*, *m*, and *p* isomers of benzyl benzoic acid and/or their benzyl esters. These products were not observed by ^{1}H NMR ($CDCl_3$) [absence of signals at δ 3.7−4.0[24c] and 5.35−5.40[24c] (other than benzyl benzoate)]. Extraction of the product mixture with aqueous base followed by neutralization and extraction with $CDCl_3$ also failed to show these signals.[27]

Effect of Reactive Diluents. When the solvent is sufficiently reactive with respect to the cation involved, e.g., CH_2Cl_2 for the norbornyl cation[6] or acetonitrile for the benzyl cation,[15a,16c] alkylation of the solvent occurs.[6,15a,16c] For example N-benzyl-*N*-nitrosotriflamides quantitatively benzylate acetonitrile at 25 °C to form the corresponding N-benzylnitrilium salt, though ~ 50% of the benzylation proceeded via the labile benzyl triflate.[15a]

Nitromethane, like CH_3CN, is often used as a cosolvent in the standard F−C reactions.[16a,21] The two solvents are of comparable basicity (pK_a values: $CH_3CN = -10$; $CH_3NO_2 = -12$),[24a] and it is likely that species such as the onium ion (**29**) would be formed from nitromethane in the presence of benzyl cations.[28]



29

In the decompositions of nitrosoacetamide **1a** in the presence of CD_3NO_2, dilution of the benzene−toluene

(27) Interestingly, the acidification of 1-phenyl-3-(1-phenylethyl)-triazene yields *N*-(1-phenylethyl)aniline in addition to the *o*-, *m*-, and *p*-(1-phenylethyl)anilines (White, E. H.; Maskill, H.; Woodcock, D. J.; Schroeder, M. A. *Tetrahedron Lett.* **1969**, *21*, 1713).

Table 7. Product Distribution[a] from Deaminative Benzylation of Benzene−Anisole Using *N*-benzyl-*N*-nitrosobenzamide at 80 °C as a Function of Mole Ratio of Solvents

mole ratio of benzene:anisole	equiv of Py	yields (%)			isomer distribution		
		ester	SDP's[b,c]	k_A/k_B[c,d]	*ortho*	*meta*	*para*
5:1	0	76.7	23.3	5.17	55.2	2.0	42.8
10:1	0	77.0	23.0	5.21	55.8	2.1	42.1
1:10	2	76.3	23.7	5.28	55.7	2.2	42.1

[a] Yields were measured by NMR and/or by GC; standard deviation ~0.6 for ester-SDP data, ~0.3 for isomer distributions and ~0.1 for k_A/k_B data. [b] SDP = solvent-derived product. [c] Values are normalized to equimolar benzene−anisole. [d] The ratio of the rate constants for benzylation of anisole and benzene.

mixture with nitromethane (mole fraction of CD_3NO_2 = 0.64) led to a 50% increase in the yield of alkylated aromatics as well as a 35% increase in k_T/k_B (Table 4). As the mole fraction of CD_3NO_2 was raised further to 0.84, there was a 19% decrease in % hydrocarbon but a 10% increase in k_T/k_B (Table 4). This effect of CD_3NO_2 was markedly different from that of inert diluents where the k_T/k_B was essentially constant but where the % SDP gradually fell on dilution. This difference presumably is related to the presence of secondary benzylating agents only when reactive diluents are employed.

Unlike the high-energy, first-formed deaminative benzyl cation (the *primary* benzylating agent), the *secondary* benzylating agent, **29**, would be less energetic and would effect more selective benzylations. This is of concern in mechanistic studies of the F−C reaction when reactive cosolvents are employed[20,21] because the observed product distribution may not be reflective of only the primary electrophile.[16a,c] If left uncorrected, these compromised values may lead to erroneous conclusions and hypotheses.[16a,c,e]

Deaminative Benzylations of Benzene/Anisole. *N*-Benzyl-*N*-nitrosobenzamide (**1e**) was decomposed in mixtures of benzene and anisole at 80 °C. Typically, mixtures of 10:1 and 5:1 benzene to anisole were used in order to compensate for the lower nucleophilicity of benzene relative to anisole. The results (Table 7) show an average k_A/k_B value of 5.22 which is lower than the values (~14−18) obtained from the standard Friedel−Crafts alkylations of benzene−anisole mixtures.[29] Additionally, the yield of the *meta* isomer (~2%) is larger than that observed in the standard F−C approach (<0.3%).[29] Similar trends in k_T/k_B and % *meta* were observed in the benzylation of benzene−toluene (vide supra). The higher reactivity of the deaminatively generated benzyl cation versus the benzyl electrophile formed in the standard F−C approach, leads to a less discriminative partitioning between the components in the medium.[16e] Further discussion of the k_A/k_B and % *meta* values is the subject of an upcoming article.[30a]

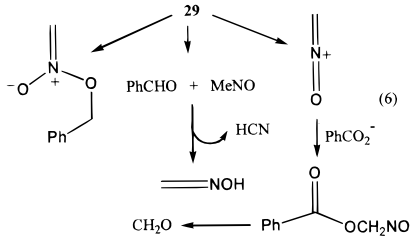
No definitive ester/SDP data are available from this series because of technical difficulties in the quantitation. Protoanisole was used in these experiments (fully deuterated anisole was not commercially available), and its methoxy signal blanketed the region in which the methoxy signals of the anisole-derived products appeared. All attempts at removal of anisole resulted in simultaneous preferential loss of diphenylmethane. Because of the irreproducibility in the values for the relative response factors for esters the GC values of ester/SDPs are not corrected for detector responses. Presumably, however, the greater nucleophilicity of anisole vs toluene would have led to greater amounts of solvent-trapped product. Indeed, the uncorrected[31] GC data available, normalized to equimolar benzene−anisole, indicate that SDPs account for ~25% of the total product vs ~7% for the decomposition of the same nitrosobenzamide (**1e**) (in both cases) in equimolar benzene−toluene at the same temperature.

Summary and Conclusions

Further evidence have been found for the intermediacy of inert-molecule-separated ion pairs in deamination. These include (1) the insensitivity of the cation to the nucleophilicity of the counterion, (2) the existence of a temperature dependence of the yield of ester, and (3) the formation of higher yields of SDP when N_2O (vs N_2) is generated as the inert molecule. Similarities in product distribution were observed for the benzylation of benzene−toluene mixtures using nitrosoamides (**1a**,**e**), nitroamides (**6**) phenyldiazomethane (**5**), and the hydroxylamine **10**. This observation indicates a familial relationship among these approaches and that the properties of the precursors are averaged out in the formation of similar intermediates.[15c,23]

Solvent alkylation is increased by decreasing the IM diffusion rate and by use of poorly nucleophilic counterions. When reactive diluents are present, secondary alkylations occur via onium-type ions[15a,16c,30b] resulting in markedly skewed data. Inert diluents exert a near statistical decrease on the yield of solvent-derived prod-

(28) The onium ion, **29**, may be capable of reactions other than benzyltransfer. Some of these reactions are shown (eq 6).



Benzaldehyde was not observed to the detection limit of the NMR (~0.01%) (absence of signal at δ 10.7 in CD_3NO_2/benzene−toluene). No signal in the region δ 4−7 was observed (except for that due to ester) so the other pathways leading to compounds containing the benzyl group also appear to be noncompetitive.

(29) Olah, G. A.; Olah, J. A.; Toshiyuki, O. *J. Am. Chem. Soc.* **1984**, *106*, 5284.

(30) (a) White, E. H.; Darbeau, R. W. In *Investigation of the Friedel−Crafts Alkylation Reaction Using Essentially Free Carbocations,* in preparation. (b) Darbeau, R. W.; White, E. H. In *The Reaction of Essentially Free Carbocations with Acetonitrile; Synthesis of Ethanimidic Carboxylic Anhydrides*, in preparation.

(31) The molecular formulas of benzyl benzoate and the isomeric methoxydiphenylmethanes are $C_{14}H_{12}O_2$ and $C_{14}H_{15}O$, respectively; thus the relative response factors, which depend partially upon carbon number, (Schomburg. G. *Gas Chromatography: A Practical Course*, 1st ed., VCH: Weinheim, Germany, 1990; p 116) are not likely to be very different from each other.

ucts. Cations recoiling from collisions with the inert diluents apparently do not always lead to ester but may also "survive" to collide with active solvent when present. These "bonus" opportunities for cation/solvent reaction while the former is still insulated from the counterion by the IM, result in a smaller than statistical decrease in the yield of SDP.

A new parameter, the ratio of ester to solvent-derived product, has been introduced as a measure of the reactivity of the cation to complement the more traditional k_T/k_B value. The former involves energetically disparate pathways while the latter reflects partitioning between energetically similar pathways. Consequently the ester/SDP ratio was more sensitive than k_T/k_B to changes in the cation, the counterion, the IM, and the temperature.

The nitrosocarboxamide approach is excellent for studying mechanisms of reactions involving carbocations because of the high reactivity of the cations, the high reproducibility of the results, and the stability of the carboxylic ester products, which are not secondary alkylating reagents under the conditions used. The reactions are clean and are easily carried out on a small scale and at a range of temperatures. Hence they represent an elegant method particularly recommended for microscale work, including reactions of chiral compounds and isotopically labeled or otherwise valuable compounds.

The yields of alkylated arenes are moderately low in some of the approaches in this study, but higher yields can be obtained through the use of weakly nucleophilic counterions such as the triflate ion. In the latter case, however, care is needed to resolve alkylation by the primary agent (the carbocation) and the secondary alkylating agent (alkyl triflate).

Experimental Section

Materials and Methods. Dinitrogen tetroxide was purchased from the Matheson Gas Co., and the other commercial reagents were from the Aldrich Chemical Co.; all were used without further purification.

NMR spectra were recorded on a Bruker AMX 300 MHz FT instrument; UV−Vis and IR spectra were measured using a Beckman model 25 UV−Vis spectrometer and a Perkin-Elmer 1600 Series FT-IR spectrometer, respectfully. The gas chromatography data were obtained using a flame ionization detector; a 30m SE−30 (i.d. 0.25 mm and film thickness 0.25 μm) column was used for GC analyses. Helium was used as the carrier gas. GC data for the 4-R-substituted diphenylmethanes and methydiphenylmethanes were obtained at 145 °C/13 psi (for R = H, Me, Cl) and at 160 °C/10 psi (for R = NO_2). All relative response factor data were obtained using the method of Rosie and Grob[32] under conditions identical to those used for the respective analyses. All syntheses and reactions of *N*-nitroso- and *N*-nitroamides as well as phenyldiazomethane were performed in the dark. In many instances, runs were performed in evacuated, sealed NMR tubes. TLC analyses were performed on UV-fluorescent silica gel plates unless otherwise stated.

Stability of the Precursors: Handling and Storage. *N*-Nitroso- and *N*-nitroamides in addition to being thermolabile are labile in the presence of acids, bases, and moisture. As a result, the dry, neutral oils were stored at −25 °C in desiccators. The compounds used in this study could be stored in this fashion for at least 1 month before detectable decomposition into ester occurred. The half-lives of these compounds vary from ∼5 h (for **1e**) to ∼40 days (for **1a**) at 25 °C in benzene−toluene. *N*-Benzyl-*O*-benzoylhydroxylamine (**10**) could be stored for months (dry and neutral) at −25 °C while phenyldiazomethane (**5**) was prepared as required and was stored only briefly (∼1 week) at −60 °C. All compounds were handled in the dark. **Caution!** *Phenyldiazomethane and nitroso- and nitroamides should be handled with extreme care because of their possible mutagenicity[33a] and carcinogenicity (local and systemic).[33b] Efficient fume hoods and appropriate personal protection (chemical-resistant gloves, safety glasses, lab coat, etc.) are recommended when handling these compounds.*

Preparations of Standards. Methyldiphenylmethanes: General Method. These were prepared by the method of Nystrom and Berger.[34a]

2-Methyldiphenylmethane: ^{1}H NMR ($CDCl_3$)δ 2.19 (s, 3H), 3.93 (s, 2H), 7.06−7.21 (m, 9H).

3-Methyldiphenylmethane: ^{1}H NMR ($CDCl_3$) δ 2.31 (s, 3H), 3.94 (s, 2H), 7.03−7.39 (m, 9H).

4-Methyldiphenylmethane: ^{1}H NMR ($CDCl_3$) δ 2.28 (s, 3H), 3.91 (s, 2H), 7.06 (s, 5H), 7.14−7.24 (AB_q 4H).

Other 4-R-Substituted diphenylmethanes (Substituent = Me, Cl) and Isomeric 4-Substituted Phenylmethyltoluenes (Substituent = Me, Cl, NO_2): General Method. The appropriately substituted benzyl chloride in 10 equiv (eq.) of benzene or toluene (freshly distilled and dried over $MgSO_4$) was added dropwise to a stirred solution of $TiCl_4$ (0.1 equiv) in 10 equiv of benzene or toluene at 25 °C (when the substituent = H or Cl), at 80 °C (when the substituent = NO_2), and −20 °C (when the substituent = Me). The solution was stirred at this temperature for ∼90 min after which the reaction was quenched with ice-cold saturated NaCl and the organic phase was extracted with ether. The solution was then washed in turn with saturated solutions of $NaHCO_3$ and NaCl and then dried over Na_2SO_4. The solution was evaporated in vacuo to yield a colorless oil.

4-Methyldiphenylmethane. t_R (145 °C/13psi) 13.1 min.

2,4′-Dimethyldiphenyl- methane. t_R (145 °C/13psi) 18.7 min.

3,4′-Dimethyldiphenylmethane. t_R (145 °C/13psi) 19.1 min.

4,4′-Dimethyldiphenylmethane. t_R (145 °C/13psi) 20.1 min.

4-Chlorodimethyldiphenylmethane. t_R (145 °C/13psi) 18.6 min.

4-Chloro-2′-methyldiphenylmethane. t_R (145 °C/13psi) 26.8 min.

4-Chloro-3′methyldiphenylmethane. t_R (145 °C/13psi) 27.5 min.

4-Chloro-4′methyldiphenylmethane. t_R (145 °C/13psi) 28.5 min.

4-Nitro-2′-methyldiphenylmethane. t_R (160 °C/10psi) 55.0 min.

4-Nitro-3′-methyldiphenylmethane. t_R (160 °C/10psi) 57.2 min.

4-Nitro-4-methyldiphenyl methane. t_R (160 °C/10psi) 58.5 min.

4-Nitrodiphenylmethane. A solution of 4-nitrobenzyl chloride (172 mg, 1 mmol) and $TiCl_4$ (11 μL, 0.1 mmol) in benzene (2 cm^3, 22 equiv) (freshly distilled and dried over $MgSO_4$) was heated with stirring at 80 °C for 48 h. The reaction was quenched with ice-cold saturated NaCl, and the organic phase was extracted with ether. The solution was then washed in turn with saturated solutions of $NaHCO_3$ and NaCl and then dried over $MgSO_4$. The solvent was removed in vacuo, and the residue was distilled at the oil pump in fractions at bath temperatures of 90−100, 100−110, and 110−120 °C. The second fraction at 110−120 °C was obtained as a bright yellow oil (53 mg, 25%). ^{1}H NMR ($CDCl_3$): δ 4.07 (s, 2H), 7.17−7.56 (m, 9H). t_R (160 °C/10 psi): 39.5 min. **Caution!** *If the reaction is performed at temperatures >85 °C or for times >48 h, large amounts of polymer form. If the reaction is not stirred briskly, the polymer deposits on the flask.*

(32) Rosie, D. M.; Grob, R. L. *Anal.Chem*. **1957**, *29*, 1263.

(33) (a) Lee, K.; Gold, B.; Mirvish, S. *Mutat. Res.* **1977**, *48*, 131. (b) Preussman, R.; Stewart, B. W. *Chemical Carcinogenesis;* Searle, C., Ed., ACS Monograph No. 182, American Chemical Society: Washington, DC, 1984; pp 643−828.

Table 8. Relative Response Factors for the Substituted Diphenylmethanes versus the Corresponding Parent Diphenylmethane[a]

sample	ref	RRF[b]
2-methyldiphenylmethane	diphenylmethane	1.12
3-methyldiphenylmethane		1.10
4-methyldiphenylmethane		1.01
2-methoxydiphenylmethane		1.02
3-methoxydiphenylmethane		1.02
4-methoxydiphenylmethane		1.04
mixture of the isomeric 4-(methylbenzyl)toluenes[c]	4-methyldiphenylmethane	1.02
		1.02

[a] Determined by the method in ref 32. [b] Relative response factor. [c] Determined for the mixture of isomers.

2-Methoxy- and 4-Methoxydiphenylmethanes: General method. The appropriate hydroxydiphenylmethane (920 mg, 5.0 mmol) was added to a stirred solution of NaOH (210 mg, 5.25 mmol) in 5 mL of water at 25 °C with stirring. Dimethyl sulfate (523 μL, 5.5 mmol) was then added with stirring over the course of 1 h after which the suspension was refluxed for 12 h. It was then cooled to 25 °C and was poured into 25 mL of NaOH (pH ~ 13) and extracted with ether. The organic layer was washed with water and then dried over $MgSO_4$; solvent removal in vacuo afforded a golden yellow oil. This crude product was distilled (bp 150−160 °C) at the oil pump producing a colorless oil (600 mg, 3 mmol, 60%).

2-Methoxydiphenylmethane: ^{1}H NMR ($CDCl_3$) δ 3.79 (s, 3H), 3.97 (s, 2H), 6.58−7.31 (m, 9H).

4-Methoxydiphenylmethane: ^{1}H NMR ($CDCl_3$) δ 3.78 (s, 3H), 3.92 (s, 2H), 6.75−7.35 (m, 9H).

Relative Response Factor Analyses. Using the method of Rosie and Grob,[32] the relative response factors (RRFs) of the individual methyldiphenylmethanes (MeDPMs) versus diphenylmethane (DPM), of the isomeric 4-methylphenylmethyltoluenes versus 4-MeDPM, and of the individual methoxydiphenylmethanes versus DPM were determined (Table 8).

Esters. 4-Methylbenzyl acetate, 4-chlorobenzyl acetate, 4-nitrobenzyl acetate, 4-methoxybenzyl acetate, 4-methylbenzyl benzoate, and benzyl tosylate were prepared by decomposition of the corresponding *N*-nitrosoamides in $CDCl_3$. In each case the major (>98%) product was the appropriate ester, but small amounts of the corresponding amides (via denitrosation[22a]) were also formed. The nitrosobenzamides also yielded a small amount (<0.1%) of the hydrocarbon via decarboxylation. The ^{1}H NMR spectra of the decomposition products were compared with the spectral data for the authentic esters from *The Aldrich Library of NMR Spectra*, 2nd ed., from *The Properties of Organic Compounds*, CRC Press Database, CD-ROM, 1993, or from *The Chemistry of Organic Compounds*, Chapman Hall Database, CD-ROM, 1982−1995.

Preparations of Reagents. *N*-Alkylacetamides and *N*-Alkylbenzamides: General Method. Following the procedure of Heyns and von Bebenburg[34b] the required benzylamine (55 mmol) in 15 cm^3 of ethyl ether was added dropwise to acetic anhydride (17.4 cm^3, 184 mmol, 3.3 equiv) with stirring over 40 min at 25 °C. The initial cloudiness dissipated after ~20 min. The solution was washed, successively with dilute H_2SO_4 (pH ~3), $NaHCO_3$, and water; it was then dried over Na_2SO_4. Removal of ether in vacuo afforded a pale yellow oil which solidified on cooling. Recrystallization from benzene−hexane yielded (80−90%) of white needlelike crystals.

***N*-Benzylacetamide:** mp 59−60 °C (lit.[35a] mp 59−60 °C); IR (Nujol) 3310, 1660 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.98 (s, 3H), 4.38 (d, 2H, J = 5.5 Hz), 5.90 (bs, 1H), 7.18−7.38 (m, 5H); UV (Et_2O) λ_{max} = 256 nm (ϵ = 97), 320 nm (ϵ = 16).

***N*-(4-Methylbenzyl)acetamide:** mp 109−111 °C (lit.[35b] mp 110−111 °C); IR ($CHCl_3$) 3310, 1660 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.01 (s, 3H), 2.34 (s, 3H), 4.39 (d, 2H, J = 5.6 Hz), 5.65 (bs, 1H), 7.05−7.20 (ABq, 4H); UV (Et_2O) λ_{max} = 256 nm (ϵ = 95), 320 nm (ϵ = 16).

***N*-(4-Chlorobenzyl)acetamide:** mp 106−108 °C (lit.[35c] mp 106−107 °C); IR ($CHCl_3$) 3305, 1657, 1075 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.03 (s, 3H), 4.40 (d, 2H, J = 5.6 Hz), 5.78 (bs, 1H), 7.23−7.31 (ABq, 4H).

***N*-(4-Nitrobenzyl)acetamide:** mp 127−129 °C (lit.[35d] mp 130−131 °C); IR ($CHCl_3$) 3305, 1655, 1250, 1050 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.01 (s, 3H), 2.34 (s, 3H), 4.39 (d, 2H, J = 5.6 Hz), 5.65 (bs, 1H), 7.05−7.20 (ABq, 4H); UV (Et_2O) λ_{max} = 293 nm (ϵ = 486), 315 nm (ϵ = 27).

***N*-Benzylbenzamide:** mp 103−104 °C (lit.[35e] 104−105 °C); IR (Nujol) 3289, 1638, 1491 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 4.65 (d, 2H, J = 5.7 Hz), 6.55 (bs, 1H), 7.29−7.50 (m, 8H), 7.80 (d, 2H, J = 6.9 Hz).

***N*-(4-Methylbenzyl)benzamide:** mp 133−134 °C (lit.[35f] 136−138 °C); IR (Nujol) 3290, 1640, 1380 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.35 (s, 3H), 4.63 (d, 2H, J = 5.7 Hz), 6.31 (bs, 1H), 7.05−7.27 (m, 3H), 7.30−7.56 (m, 2H), 7.82 (d, 2H, J = 7.0 Hz).

***N*-Benzyl-*N*-4-toluenesulfonamide.** Following the procedure of Holmes and Ingold,[36] benzylamine (20 g, 0.19 mol) was dissolved in pyridine (75 cm^3, 0.93 mol) and *p*-toluenesulfonyl chloride (40 g, 0.21 mol) was added with stirring over 30 min at 25 °C. After complete addition, the warm, red solution was stirred for a further 1 h; it was then poured into 150 cm^3 of water, and the white/yellow precipitate that formed was filtered out and dried at oil pump vacuum. The solid was then recrystallized from ethanol to yield (45%) yellow crystals: mp 111−113 °C (lit.[36] mp 113−114 °C); IR (KBr) 3269, 1598, 1454, 1094, 1028 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.43 (s, 3H), 4.11 (d, 2H, J = 7.1 Hz), 4.28 (bs, 1H), 7.17−7.31 (m, 7H), 7.74−7.77 (d, 2H, J = 9.0 Hz).

***N*-Alkyl-*N*-nitrosoamides (1a−f): General Method.** Following the method of White et al.,[15d] an ice-cold suspension of NaOAc (1.44 g, 15 mmol, 10 equiv) and N_2O_4 (l) (0.5 cm^3, 8.1 mmol) was treated with a solution of the appropriate *N*-alkylamide (1.5 mmol) in 2.5 cm^3 CH_2Cl_2. After being stirred for 1 h at 0 °C, the suspension was washed successively with ice cold saturated solutions of NaCl, Na_2CO_3, and NaCl. The organic phase was dried over Na_2SO_4 and the solvent removed in vacuo. Yellow oils (1.5 mmol, 100%) were obtained.

***N*-Benzyl-*N*-nitrosoacetamide (1a):** IR (Nujol) 1725, 1605, 1502, 1372 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.80 (s, 3H), 4.92 (s, 2H), 7.18−7.28 (m, 5H); UV (CH_3CN) λ_{max} = 425 nm (ϵ = 66), 405 nm (ϵ = 63), 394 nm (sh).

***N*-(4-Methylbenzyl)-*N*-nitrosoacetamide (1b):** IR (Nujol) 1725, 1609, 1502, 1375 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.29 (s, 3H), 2.78 (s, 3H), 4.88 (s, 2H), 7.08−7.10 (m, 4H).

***N*-(4-Chlorobenzyl)-*N*-nitrosoacetamide (1c):** IR (Nujol) 1725, 1600, 1502, 1375 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.80 (s, 3H), 4.88 (s, 2H), 7.14−7.25 (ABq, 4H); UV (Et_2O) λ_{max} = 420 nm (ϵ = 22), 405 nm (ϵ = 124), 392 nm (sh), 289 nm (ϵ = 312).

***N*-(4-Nitrobenzyl)-*N*-nitrosoacetamide (1d):** IR (Nujol) 1720, 1575, 1355 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.85 (s, 3H), 5.01 (s, 2H), 7.24−8.22 (ABq, 4H).

***N*-Benzyl-*N*-nitrosobenzamide (1e):** IR (Nujol) 1719, 1609, 1502, 1375 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 5.14 (s, 2H), 7.36−7.60 (m, 10H).

***N*-(4-Methylbenzyl)-*N*-nitrosobenzamide (1f):** IR (Nujol) 1720, 1610, 1510, 1375 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.31 (s, 3H), 5.08 (s, 2H), 7.09−7.76 (m, 9H).

***N*-Benzyl-*N*-nitroso-4-toluenesulfonamide (24):** Following the procedure of Overberger and Anselme,[37] a solution of *N*-benzyl-4-toluenesulfonamide (10.5 g, 40 mmol) in glacial acetic acid (50 cm^3) and acetic anhydride (200 cm^3) at 0 °C was treated with powdered sodium nitrite (60 g, 85 mmol) over the course of 3 h. The resultant green mixture was stirred at

(34) (a) Nystrom, R. F.; Berger, C. R. A. *J. Am. Chem. Soc.* **1958**, *80*, 2896. (b) Heyns, K.; v. Bebenburg, W. *Chem. Ber.* **1953**, *86*, 278.

(35) (a) *Beilstein*; Vol. 12, 2nd Suppl., p 588. (b) *Beilstein*; Vol. 12, 3rd Suppl., p 2522. (c) *Beilstein*; Vol. 12, 3rd Suppl., p 2346. (d) *Beilstein*; Vol. 12, 3rd Suppl., p 2369. (e) *Beilstein*; Vol. 12, 3rd Suppl., p 2259. (f) *Beilstein*; Vol. 12, 4th Suppl., p 2577.

(36) Holmes, E. L.; Ingold, C. K. *J. Chem. Soc.* **1925**, *127*, 1800.

(37) Overberger, C. G.; Anselme, J. *J. Org. Chem.* **1963**, *28*, 592.

0 °C for a further 12 h; it was then poured into 500 cm^3 ice cold water. The pale yellow precipitate that formed was filtered out, washed with water (×3), and dried at oil pump vacuum. Recrystallization from ether−ethanol yielded 8.8 g (76%) of yellow crystals: mp 88−90 °C (lit.[37] mp 88−90 °C); IR (KBr) 1596, 1497, 1384, 1196 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.41 (s, 3H), 4.93 (s, 2H), 7.11−7.27 (m, 7H), 7.71−7.74 (d, 2H, $J = 9.0$ Hz); UV (Et_2O) $\lambda_{max} = 289$ nm ($\epsilon = 500$), 391 nm ($\epsilon = 15$), 409 nm ($\epsilon = 15$).

***N*-Benzyl-*N*-nitroacetamide (6)**:[38] was obtained with kind permission from Dr. F. Song. ^1H NMR ($CDCl_3$): δ 2.69(s, 3H), 5.27 (s, 2H), 7.15−7.40 (m, 5H).

***N*-Benzyl-*O*-benzoylhydroxylamine (10).** Following the procedure of Zinner,[39] benzylamine (22.7 g, 100 mmol) dissolved in 10 cm^3 of benzene was added dropwise with stirring to a solution of benzoyl peroxide (12.1 g, 50 mmol) in benzene at 0 °C. After complete addition, the yellow solution was allowed to warm to 30 °C and was maintained at that temperature for 30 min. It was then warmed to 50 °C and maintained there for a further 50 min. The solution was then cooled to 25 °C and then to 0 °C when precipitation occurred. After removal of the precipitated benzylammonium benzoate, the filtrate was treated with dry HCl in batches. (This procedure was employed to effect selective precipitation of the more basic hydroxylamine rather than the amide.) The white precipitate that formed was filtered off and was dissolved in 1 M Na_2CO_3. The resulting solution was extracted with ether, dried, and evaporated in vacuo to yield (50−55%) of a golden yellow oil: IR ($CHCl_3$) 1725 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.28 (s, 2H), 7.29−7.97 (m, 9H), 7.96−8.00 (d, 2H, $J = 12$ Hz).

Benzaldehyde Tosylhydrazone. Following the procedure of Closs and Moss,[40] tosylhydrazine (18.6 g, 0.1 mol) was dissolved in 90 cm^3 of boiling methanol. The methanolic solution was cooled to 50 °C and added dropwise with stirring to benzaldehyde (10.2 cm^3, 0.1 mol) in 10 cm^3 methanol at 0 °C over the course of 30 min (care being taken for the reaction temperature to remain below 50 °C). After complete addition, the pale yellow solution was stirred for a further 15 min at 0 °C. Solid appeared after ∼5 min. The suspension was cooled to −78 °C for 2 h; it was then filtered, and the residue was recrystallized from boiling methanol and dried at oil pump vacuum to afford 15 g (55%) of white crystals: mp 129−130 °C (lit.[40] 130−131 °C); ^1H NMR ($CDCl_3$) δ 2.40 (s, 3H), 7.28−7.65 (m, 7H), 7.76 (s, 1H), 7.87−7.89 (d, 2H, $J = 6.0$ Hz), 8.00 (bs, 1H).

Phenyldiazomethane (5) was prepared by two methods; the first method always yielded a minimum of 2% *trans*-stilbene. Additionally, the quantity of stilbene varied uncontrollably from 2% to ∼10%. The second method was preferred because it consistently yielded stilbene-free product: IR (CCl_4) 2060 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.93 (s, 1H) 7.04 (t, 2H), 7.26 (m, 3H).

Method 1.[40] Sodium (100 mg, 4.3 mmol) was rinsed in pentane and added to 10 cm^3 of absolute ethanol at 25 °C. When hydrogen evolution was finished, benzaldehyde tosylhydrazone (550 mg, 1.89 mmol) was added and the suspension heated at 65 °C for 40 min in the dark until no more solid was evident. The deep red solution was poured into 40 cm^3 of ice-cold water and extracted with 20 cm^3 of pentane. The solution was dried and evaporated in vacuo in the dark at 0 °C. It was then distilled at oil pump vacuum, and collected in a reservoir at ∼−60 °C.

Method 2.[41] **Part A.** Sodium (58 mg, 2.52 mmol, 2.05 equiv) was rinsed in pentane and then added under N_2 to methanol (2.5 cm^3). After dissolution, benzaldehyde tosylhydrazone (0.34 g, 1.23 mmol) was added; when all the solid dissolved, the pale yellow solution was evaporated in vacuo and then at oil pump vacuum to produce the off-white solid sodium benzaldehyde tosylhydrazone (0.36 g, 1.23 mmol, 100%).

(38) Synthetic details will be published separately.[30a]
(39) Zinner, G. *Arch. Pharm.* (*Weinheim, Ger.*) **1963**, *296*, 57.
(40) Closs, G. L.; Moss, R. A. *J. Am. Chem. Soc.* **1964**, *86*, 4042.
(41) Creary, X. *Org. Synth.* **1986**, *64*, 207.

Part B. Sodium tosylhydrazone was heated in an oil bath at 90−100 °C at oil pump vacuum, and the product phenyldiazomethane was collected in a receiving tube at ∼−60 °C.

Decompositions of N-alkyl-*N*-nitrosoamides. In a typical run ∼5 mg of nitrosoamide and 2 equiv of pyridine (or 2,6-di-*tert*-butyl-4-methylpyridine for **24**) were dissolved in 500 μL of solvent (usually equimolar benzene−toluene or a mixture containing it, but anisole, $CDCl_3$, cyclohexane, and other solvents were used as required). The solution was placed in an NMR tube that was then attached to a special holder on a vacuum line. Prior to evacuation at oil pump vacuum, the solution was frozen in liquid N_2, then degassed, and finally evacuated again and flame-sealed while still under vacuum. The sealed tube was then incubated at the necessary temperature until decomposition was complete (as verified by the absence of starting material by NMR).

Acidification of Phenyldiazomethane (5) in Benzene−Toluene. In a typical run, a solution of freshly prepared **5** (2.5 μL, 23.6 μmol), devoid of *trans*-stilbene (absence of signal at δ 6.93 in $CDCl_3$), in 100 μL of equimolar benzene−toluene was added with stirring to a solution of benzoic acid (10 mg, 83 μmol) and pyridine (26.8 μL, 166 μmol) in 400 μL of equimolar benzene−toluene at 25 °C in the dark. The red color dissipated completely in ∼2 s. The Teflon-coated magnetic stirring bar was prerinsed in dilute HNO_3 followed by $NaHCO_3$ and then by cold water. The acid rinse was used to remove trace ferromagnetic materials from the bar; the other rinses removed the acid and salts (+ excess base), respectively. This reaction was found to be limited by two major variables. *(1) Acid strength*: Pyridine must be present during all of the deaminative runs to eliminate an impurity (vide infra) which interferes with *meta*/*ortho* resolution in the GC; the acid which is used with phenyldiazomethane (**5**) must be sufficiently weak to allow the existence of intact pyridine (as distinct from the apparently ineffective pyridinium ion). Thus carboxylic, but not sulfonic acids, can be used. *(2) Temperature*: Phenyldiazomethane (**5**) is thermolabile and readily decomposes at elevated temperatures; even storage at 25 °C for a few hours leads to detectable formation of *trans*-stilbene. On the other hand, acidifications performed at or below 0 °C are prohibitively slow even with triflic acid. Thus a fairly narrow temperature window exists for working with **5**.

Nitrosation of *N*-benzyl-*O*-benzoylhydroxylamine (10). In a typical nitrosation at 0 or 25 °C, N_2O_4(g) (0.23 cm^3, 9.5 μmol, 0.5 equiv) was injected rapidly into a stirred solution of **10** and pyridine (3.1 μL, 37.8 μmol) in 500 μL of benzene−toluene in a round-bottom flask (the stir bar was pretreated as described above). The reaction was instantaneous; a white precipitate of pyridinium nitrate was evident. In a typical low-temperature run, N_2O_4(g) (0.23 cm^3, 9.5 μmol, 0.5 equiv) was injected as above into a stirred solution of **10** and 2 equiv pyridine in toluene at −78 °C. The reaction was instantaneous.

A. Lability of *N*-benzyl-*N*-nitroso-*O*-benzoylhydroxylamine (11). *N*-Benzyl-*O*-benzoylhydroxylamine (**10**) (5 mg, 22 μmol) and pyridine (3.6 μL,44 μmol) were dissolved in a mixture of furan (150 μL) and $CDCl_3$ (350 μL) in an NMR tube. The solution was cooled to −80 °C in the NMR probe and was treated with N_2O_4(g) (0.27 cm^3, 11 μmol). No signal which decreased in intensity on warming was observed. Further, the *C*-benzylfurans (δ 4.01 and 3.68) were present at the first NMR scan after nitrosation (time elapsed ∼1 min). Thus *N*-benzyl-*N*-nitroso-*O*-benzoylhydroxylamine (**11**) is too labile to be detected by NMR at −80 °C[6] and either the *O*-benzylfuranonium ion is too labile to be detected under these conditions, or it does not form under these conditions.

B. Formation of Benzyl Nitrate. When *N*-benzyl-*O*-benzoylhydroxylamine (**10**) was nitrosated with N_2O_4, a variable quantity (5−10%) of benzyl nitrate (δ 4.64 in benzene−toluene) was produced through reaction of the benzyl cation and nitrate ions from N_2O_4 + **10** (or H_2O). The yield of nitrate ester is minimal (∼5%) if the N_2O_4 is introduced with vigorous stirring. The yield of nitrate ester is included in computations of ester/hydrocarbon data.

Table 9. Effect of Quantity of N_2O_4 on Yields[a] in Nitrosation of 10[b] in Equimolar Benzene−Toluene

			yields (%)		
	equiv of N_2O_4	temp (°C)	ester	SDP[c]	k_T/k_B
10	0.5−0.75	25	84.7	15.3	2.59
10	1.25−2.0	25	85.0	15.0	2.60

[a] Data averaged from at least 4 runs; standard deviation for ester/SDP data ~0.5; standard deviation for $k_T/k_B = 0.10$. [b] **10** = *N*-benzyl-*O*-benzoylhydroxylamine. [c] SDP = Solvent-Derived Product.

C. Effect of the Quantity of N_2O_4. The relative yields of products appear to be insensitive to the amount of N_2O_4 used (Table 9).

D. Benzyl Alcohol and Benzyl Nitrate as Potential Secondary Benzylating Agents. In the presence of water, benzyl alcohol as well as benzyl nitrate are formed during nitrosation of *N*-benzyl-*O*-benzoylhydroxylamine (**10**). It was possible that one or both of these side products could cause 2° benzylation of benzene−toluene under standard GC conditions (injector temperature = 250 °C, column temperature = 145 °C). To test this hypothesis, a solution of benzyl alcohol in toluene was injected on the GC under the standard GC conditions; no MeDPMs were observed. It was concluded therefore that benzyl alcohol does not cause 2° benzylation of toluene, and, by extension, of benzene, under the GC conditions used. A product mixture from the nitrosation of **10** with N_2O_4 was analyzed by GC ($k_T/k_B = 2.56$, % *ortho* = 45.7, % *meta* = 14.5, % *para* = 39.8) and was then treated with lithium aluminum hydride for 2 days at 25 °C. Both the benzoate and nitrate esters were absent (absence of signals at δ 5.37 and 4.64, respectively). Their reduction product was the innocuous benzyl alcohol (δ 4.33). The reduction product was then reanalyzed by GC ($k_T/k_B = 2.55$, % *ortho* = 45.9, % *meta* = 14.4, % *para* = 39.7). The statistically identical data before and after reduction confirm that benzyl nitrate is also inactive as a secondary benzylating agent during GC analysis.

Resolution of the Hydrocarbons by ^{1}H NMR. At 25 °C, in equimolar benzene−toluene, the MeDPMs appear as a single peak (δ 3.74), which is partially resolved from the upfield DPM (δ 3.72). Using Gaussian modifications,[42] reliable k_T/k_B data are obtained at 25 °C to compliment the values obtained by GC analyses. The values for k_T/k_B by GC and NMR are essentially the same within experimental error. As the temperature is lowered to −10 °C, the signal for the *ortho*-isomer partially resolves from the *m*/*p* signal and appears at ~ δ 3.73, between the latter and DPM. Cosolvents such as $CDCl_3$, CD_3CN, CD_3NO_2, and cyclohexane-d_{12} were found to partially resolve one of the isomers from the other two so that three peaks were observed at 25 °C. With $CDCl_3$ and cyclohexane-d_{12} the resolved isomer was determined by spiking to be the *ortho*-isomer. Attempts to enhance the resolution of the isomers by NMR by varying the temperature between −30 and 40 °C in the presence of these two cosolvents were not successful. With the other series of 4-R-substituted benzyl toluenes (R = Me, Cl, NO_2) the substituted 4-R-MeDPMs were well resolved from the 4-R-DPM so no Gaussian modifications[42] were necessary; however, there was still no resolution of the isomers.

Proof of the Absence of Benzene from Solvents. Both NMR (absence of singlet at δ 7.05) and GC (absence of signal at t_R= 6.41 min at 100 °C/5 psi) analyses verified the absence of benzene in $CDCl_3$. The absence of benzene in CH_2Cl_2, cyclohexane, and pentane was shown by GC (absence of signal at t_R= 6.41 min at 100 °C/5 psi) analyses.

Proof of the Presence of Diphenylmethane as a Reaction Product. The presence of DPM in the product was determined by NMR [presence of singlet at δ 3.95 (in $CDCl_3$)], GC (presence of signal at t_R= 9.00 min at 145 °C/13 psi), and GC/MS [*m*/*e* 168 (100), 167 (73), 165 (26), 91 (16), 152 (13), 169 (11), 153 (10)] analyses.

Proof of Kinetic Control in the Product Distribution. *N*-Benzyl-*N*-nitrosobenzamide **1b** was thermolyzed in benzene−toluene at 40 °C, and active **1b** was destroyed with $LiAlH_4$[43] after 30% completion.[44] Analysis of the products gave results that were statistically indistinguishable from the data obtained after 100% reaction. In addition, the product mixtures from three separate (completed) runs, a nitrosation of *N*-benzyl-*O*-benzoylhydroxylamine, **10**, at 25 °C, an acidification of phenyldiazomethane, **5**, at 25 °C, and a thermolysis of *N*-benzyl-*N*-nitrosoacetamide (**1a**) at 80 °C (all in equimolar benzene−toluene), were heated at 100 °C for an additional 2 days. The resultant data (ester/hydrocarbon, k_T/k_B, and isomer distribution) were not significantly different from those obtained prior to incubation at 100 °C.

Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, and to the D. Mead Johnson Foundation for support of this research. The authors also acknowledge Dr. Alex Nickon and Dr. Thomas Lectka for use of a gas chromatograph. The technical assistance of Dr. Charles Long with the NMR spectrometer is greatly appreciated, as are the efforts of Dr. Yulong Chen.

JO990494M

(42) Gaussian modification increases the resolution between partially overlapping signals by correcting for line broadening and Gaussian broadening (Lifshits, M. A. *Mathematics and its Applications; Vol 322, Gaussian Random Functions*; Kluwer Academic Publishers: Boston, MA, 1995, p 22).

(43) Saavedra, J. E. *J. Org. Chem.* **1979**, *44*, 860.

(44) Determined by ^{1}H NMR spectroscopy.