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SbF_5-Mediated Reactions of Oxafluorodiazirines

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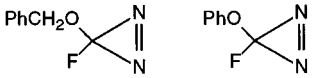
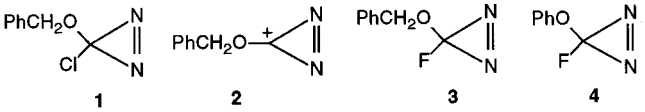
ABSTRACT



The reaction of benzyloxyfluorodiazirine (3) with SbF_5 in benzene gives $PhCH_2OCF$, which undergoes SbF_5-mediated fragmentation to $PhCH_2^+$, CO, and SbF_6^-; the benzyl cation alkylates benzene to yield diphenylmethane. Phenoxyfluorodiazirine (4) reacts with SbF_5 in benzene to give PhOCF and (ultimately) triphenylmethane by a pathway that avoids fragmentation.

We recently reported that the reaction of, for example, benzyloxychlorodiazirine (**1**) with $AlCl_3$ in benzene preferentially proceeds by Lewis acid attack at the diazirine N electron pair, rather than at Cl.[2] The sequelae include, $AlCl_3$-mediated nitrogen loss affording benzyloxychlorocarbene ($PhCH_2OCCl$), fragmentation of the carbene to benzyl cation, and alkylation of solvent benzene by $PhCH_2^+$ yielding diphenylmethane. No evidence could be found for competitive chloride abstraction by $AlCl_3$ to generate the benzyloxydiazirinium cation (**2**).[2] Evidence for diazirinium cations



1 **2** **3** **4**

remains stubbornly absent,[3] despite their potential involvement in the Graham oxidation of amidines to halodiazirines.[4]

In a renewed attempt to generate diazirinium ions, we have now subjected the reactions of benzyloxyfluorodiazirine (**3**) and phenoxyfluorodiazirine (**4**) with SbF_5 to experimental and computational scrutiny. These substrates were selected to parallel previously studied oxachlorodiazirines.[2] Perhaps the fluorophilic SbF_5 might favor *F*-attack over *N*-attack with oxafluorodiazirines **3** and **4**. In the event, we encountered an unanticipated SbF_5-mediated fragmentation of benzyloxyfluorocarbene.

Diazirines **3** and **4** were prepared by fluoride exchange reactions[5] of the corresponding chlorodiazirines;[4] experimental details have been published.[4b,5−7] Diazirine **3** was stirred with a ~20-fold excess of SbF_5 (50 wt % on graphite) in the dark at 25 °C for 1 h, whereupon the SbF_5/C was removed by filtration and UV spectroscopy revealed that **3** (355 nm) was gone. Capillary GC analysis and GC-MS indicated the presence of 77% of diphenylmethane (DPM) and 10% of triphenylmethane (TPM), eq 1.[8] The absolute yield of DPM, relative to an internal dodecane standard, was 36%.

(1) (a) Rutgers University. (b) National Cancer Institute at Frederick.

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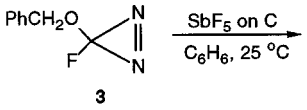
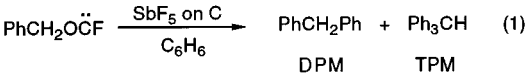


3



(1)

The principal reaction of **3** with SbF_5 thus parallels the reaction of **1** with $AlCl_3$ and can be formulated analogously: **3** is converted to benzyloxyfluorocarbene ($PhCH_2OCF$) by SbF_5 (see below), the carbene largely fragments to benzyl cation, CO, and fluoride, and the cation then alkylates solvent benzene, affording DPM. (Controls demonstrate that benzyl fluoride formed by the fragmentation would undergo SbF_5-catalyzed Friedel−Crafts reaction with the solvent.) We will return to the TPM-forming pathway of eq 1 below.

The fragmentation of $PhCH_2OCF$ in eq 1 is striking and unexpected; in the absence of SbF_5, the carbene resists fragmentation. Thus, the computed activation energy (vacuum) for the fragmentation of $PhCH_2OCF$ is 27 kcal/mol, compared to only 6.7 kcal/mol for $PhCH_2OCCl$.[9] Indeed, thermolysis at 80 °C or photolysis of **3** in MeCN is reported to give less than 10% of $PhCH_2F$ by fragmentation. Benzyl difluoromethyl ether ($PhCH_2OCHF_2$) and benzyl formate are the major reaction products, resulting from HF or water capture of $PhCH_2OCF$, respectively.[7]

Repetitions of these experiments in benzene also afforded scant carbene fragmentation, although the product mixtures were complex. Thermolysis of **3** in benzene at 100 °C in the dark gave (inter alia) 5.3% of $PhCH_2F$, 27% of benzaldehyde, 24% of $PhCH_2OCHF_2$, and 16% of benzyl formate. Photolysis of **3** in benzene gave 1.3% of $PhCH_2F$, 5% of $PhCH_2OCHF_2$, 5% of benzaldehyde, 2.4% of benzyl formate, 1.7% of DPM, 34% of carbene ($PhCH_2OCF$) dimers, and 39% of bibenzyl. The latter, apparently formed by an unknown radical process, is totally absent in the SbF_5-catalyzed decomposition of **3**, eq 1. Benzaldehyde (origin unknown) is also absent in the SbF_5-induced reaction. Clearly, the relatively clean formation of DPM here must be the result of SbF_5 mediation.

Phenoxyfluorocarbene (PhOCF) is also resistant to fragmentation: the computed E_a(vacuum) = 41.8 kcal/mol,[9] and,

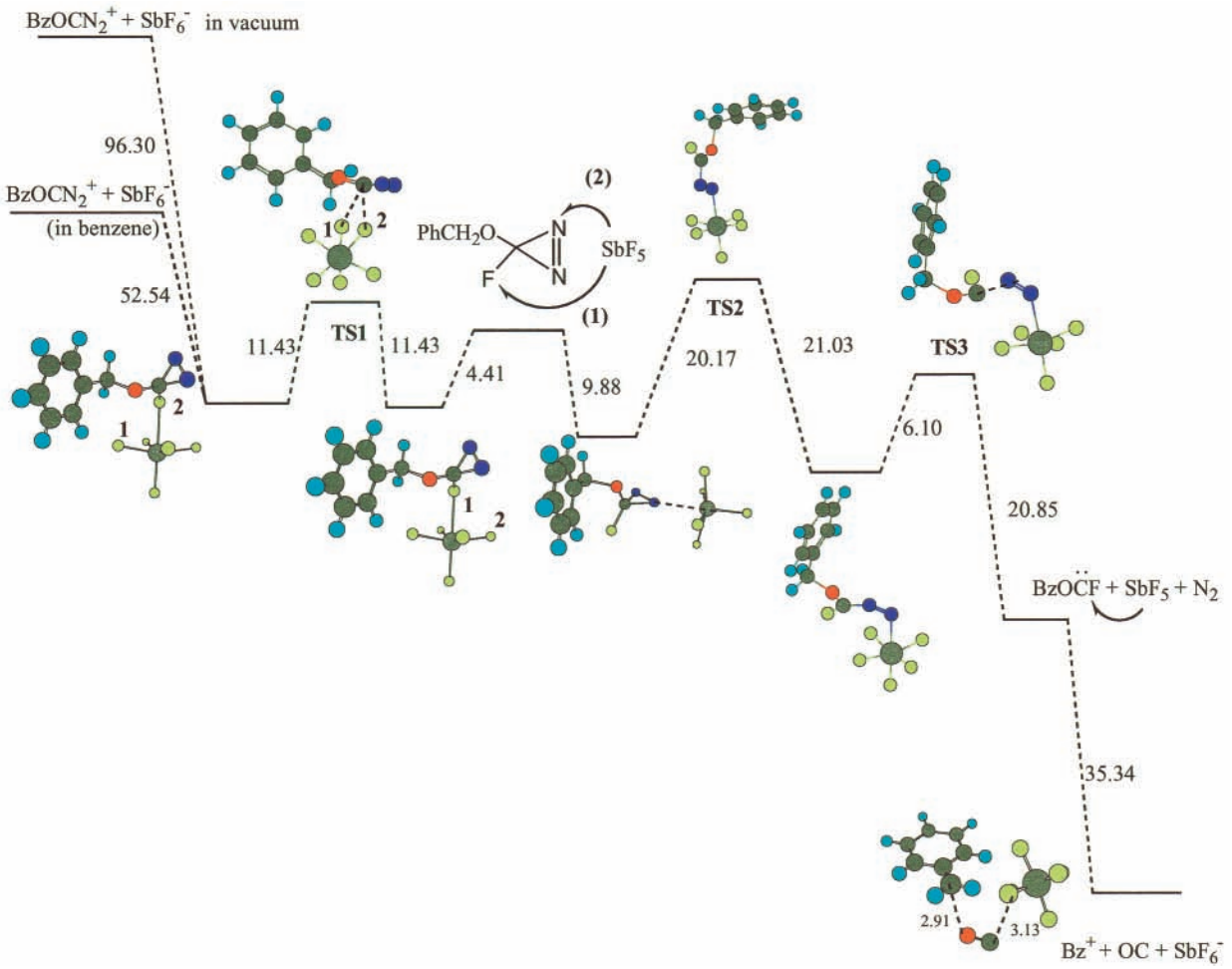


Figure 1. B3LYP/6-31G* reaction profile for the SbF_5-mediated conversion of diazirine **3** to the benzyl cation. Calculations are for the gas phase with zero point energy and thermal corrections.[11] Arabic numerals refer to energies (kcal/mol), unless they appear next to (dashed) bonds, where they represent separations (Å).

experimentally, the intact carbene can be readily captured by various alkenes.[6] When diazirine **4** is stirred with excess SbF_5/C in benzene (32 °C, dark, 6 h), TPM is formed in >95% purity.[10] In contrast, the photolysis of **4** in benzene gave mainly the HF trapping product, $PhOCHF_2$, and dimers of PhOCF. TPM formation from the reaction of **4** with SbF_5 in benzene is analogous to the reaction of phenoxychlorodiazirine with $AlCl_3$ in benzene, which also gives TPM.[2] The origin of this product is discussed below.

Computational studies were performed to evaluate mechanistic possibilities for the reactions of **3** with SbF_5. B3LYP/6-31G* techniques afforded the results summarized in Figure 1.[11] We readily located two complexes formed by SbF_5 bonding to diazirine **3** at either fluorine (1) or nitrogen (2); these complexations were exothermic by 4.4 or 9.9 kcal/mol, respectively.

The *F*-complex undergoes a facile "*F*-interchange" reaction over a barrier (TS 1) of 11.4 kcal/mol; details of the *F*-complex and TS 1 appear in Figure 2. The *F*-interchange

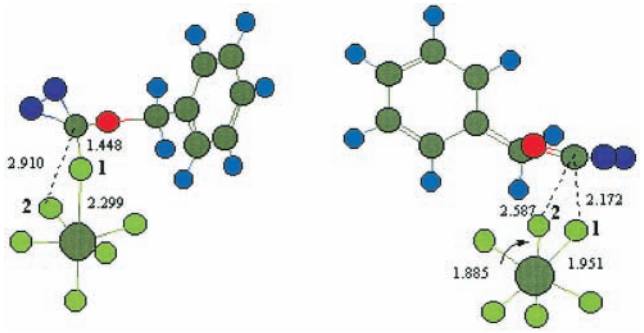


Figure 2. Details of the computed SbF_5−diazirine **3** *F*-complex (left) and TS 1 for the *F*-interchange reaction (right).[11] Bond lengths and separations are in Å.

reaction, however, appears to be a cul-de-sac for the *F*-complex. Ionization to diazirinium ion **2** and SbF_6^- would require 96 kcal/mol in a vacuum or 52.5 kcal/mol in benzene (PCM calculation) and is prohibitively endothermic (although the cost of ionization is reduced to 12.7 kcal/mol in MeCN). Nor could we locate a transition state for the simultaneous rupture of the *F*-complex into the benzyl cation, CO, N_2, and SbF_6^-, which would be exothermic by ~26 kcal/mol in benzene.

The *N*-complex of diazirine **3** and SbF_5, in contrast, does lead to products; cf., Figure 1. In analogy to the $AlCl_3$-mediated reactions of chlorodiazirines,[2] the *N*-SbF_5 complex opens to a SbF_5 complex of *linear* benzyloxyfluorodiazomethane, traversing TS 2 and a barrier of ~20 kcal/mol (net E_a = 10.3 kcal/mol from **3**).[12] The diazo complex next loses N_2 via TS 3 (E_a = 6.1 kcal/mol), affording $PhCH_2OCF$ with a net exothermicity of 14.7 kcal/mol. The overall effect of the SbF_5, therefore, is to catalyze the loss of nitrogen from **3**, generating benzyloxyfluorocarbene.

Although $PhCH_2OCF$ resists fragmentation when generated photochemically or thermally (see above and ref 7), SbF_5 mediates this process. Computational studies[11] indicate that the binding of SbF_5 at the carbene's F atom initiates fragmentation to $PhCH_2^+$, CO, and SbF_6^- with *no* barrier. Figure 3 depicts the carbene and an early stage in the

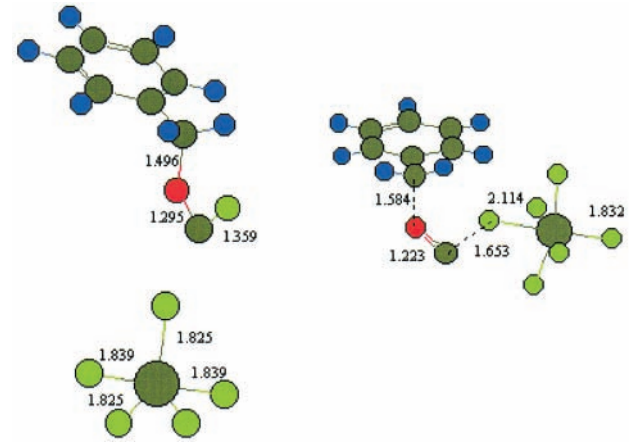


Figure 3. Computed structures[11] for benzyloxyfluorocarbene and SbF_5 (left) and for an early stage during the fragmentation of the $PhCH_2OCF$−SbF_5 complex (right); bond lengths and separations are in Å.

fragmentation of the $PhCH_2OCF$−SbF_5 assembly. Finally, the benzyl cation generated by the fragmentation alkylates the benzene solvent to give DPM.

TPM is the sole product of the reaction of diazirine **4** and SbF_5 in benzene, and a small quantity of TPM accompanies DPM formation from diazirine **3** and SbF_5. The TPM production can be rationalized by the mechanism outlined in Scheme 1, which resembles one offered for the analogous reaction of phenoxychlorodiazirine and $AlCl_3$ in benzene.[2]

Thus, SbF_5 first converts diazirine **4** to PhOCF in the same way that it generates $PhCH_2OCF$ from diazirine **3** (cf., Figure 1). Next, PhOCF (which resists fragmentation[6,7,9]) reacts with SbF_5 at the carbene carbon to give the antimony-substituted carbocation **5**,[13] which alkylates benzene via intermediate **6**. Continuations from **6** include (a) loss of HF affording the phenoxyphenylpentafluoroantimony carbocation **7**, which alkylates benzene to give $Ph_2(PhO)CH$ (**10**),[14] (b) loss of $HSbF_6$ to give phenoxyphenylcarbene (**8**), which is captured

(8) DPM and TPM were verified by GC-spiking experiments with authentic samples. Two unidentified components (5% and 8% of the total GC integrals) were also present.

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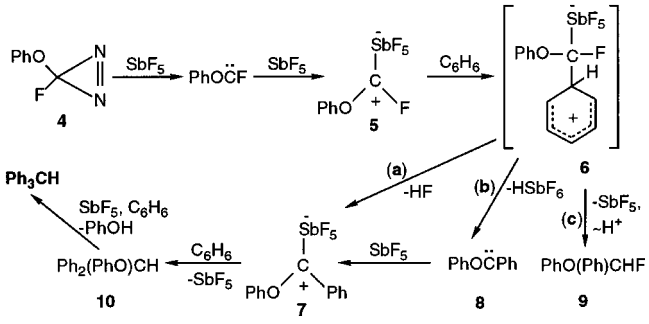
(10) Diazirine **4** did not react with SbF_5/C at 25 °C. No reaction occurred at 32 °C in the *absence* of SbF_5/C.

(11) (a) All optimizations utilized Gaussian98, Revision A.7, with default convergence criteria; Gaussian, Inc.: Pittsburgh, PA, 1998. The LANL2DZ basis set was used for Sb. (b) DFT calculations used Becke's three-parameter hybrid method with the LFP correlation functional: Becke, A. D. *J. Chem. Phys.* **1993**, *98*, 5648.

(12) The gas phase activation energies cited here would likely be lower in benzene solution. Although we did not locate a transition state for the thermal decomposition of **3** to $PhCH_2OCF$ and N_2, this conversion is computed to be endothermic by 22.96 kcal/mol in a vacuum (B3LYP/6-31G*). The SbF_5-mediated process is at least 12.7 kcal/mol less endothermic.

Scheme 1



by SbF_5 to give cation **7** and thence **10**, and (c) loss of SbF_5, coupled with a proton shift to yield phenoxyphenylfluoromethane (**9**), from which a SbF_5-catalyzed Friedel−Crafts reaction with benzene would also lead to **10**. Finally, SbF_5 attack on an oxygen lone pair of **10** would initiate another Friedel−Crafts reaction (with phenoxide as the leaving group) in which benzene is alkylated to TPM.

The mechanism of Scheme 1 not only accounts for TPM formation from **4** and SbF_5 in benzene but it also rationalizes the TPM side product formed in the analogous reaction of diazirine **3**. Thus, although $PhCH_2OCF$ mainly reacts with SbF_5 at F, initiating carbene fragmentation (77%), competitive trapping at carbenic C would lead to **5** ($PhCH_2O$ in place of PhO), initializing a cascade of reactions analogous to those in Scheme 1 and terminating in TPM (10%).

In summary, the reaction of SbF_5 with benzyloxyfluorodiazirine (**3**) in benzene yields $PhCH_2OCF$, which affords benzyl cation from a subsequent SbF_5-mediated fragmentation; the benzyl cation then alkylates benzene, giving diphenylmethane. Phenoxyfluorodiazirine and SbF_5 in benzene react to produce PhOCF. This carbene resists fragmentation, even in the presence of SbF_5, but reacts with the latter at its carbenic center, affording an antimony-substituted carbocation which starts a chain of benzene alkylation reactions that terminates in triphenylmethane. However, the novel chemistry described here does not include evidence for the intermediacy of diazirinium cations.

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(13) Attack of SbF_5 at the carbenic center of PhOCF is computed to afford **5** with an exothermicity of 34.1 kcal/mol in benzene. The alternative attack at F affords a PhOCF−SbF_5 complex with an exothermicity of 9.0 kcal/mol. However, this complex requires an activation energy of 13.3 kcal/mol for fragmentation (to Ph^+), so that it presumably reverts to PhOCF + SbF_5 and then to **5**.

(14) Greater detail, including an intermediate analogous to **6**, could be drawn for this step; only an abbreviated rendering appears in Scheme 1.