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Nucleophilic Perfluoroalkylation of Aldehydes, Ketones, Imines, Disulfides, and Diselenides

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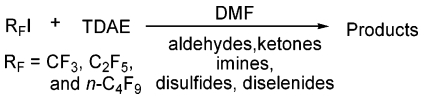
Received February 7, 2006



Using a procedure analogous to that developed for nucleophilic trifluoromethylation, the perfluoroalkyl anion reagents created by mixing C_2F_5I and n-C_4F_9I with tetrakis(dimethylamino)ethylene (TDAE) were effective in their nucleophilic reactions with aldehydes, ketones, imines, disulfides, and diselenides. Irradiation proved beneficial in the aldehyde and ketone reactions.

Introduction

During the last five years, we have published a number of papers demonstrating the broad scope of nucleophilic trifluoromethylation reactions undergone by the trifluoromethyl anion reagent derived directly from the reduction of trifluoromethyl iodide by tetrakis(dimethylamino)ethylene (TDAE). In this series of papers, simple and efficient procedures for the reaction of this relatively stable, but reactive, trifluoromethyl anion species with aldehydes and ketones,[1] imines,[2] acyl chlorides,[3] cyclic sulfates,[4] and disulfides[5] have been reported. As has been discussed in these papers and elsewhere,[6] the trifluoromethyl anion reagent derived from CF_3I/TDAE is *comparable* in utility in most essential aspects to the popular reagent developed largely by the Prakash group that is derived from CF_3TMS,[7−10] similar CF_3^- anion reagents developed by the Langlois group[11] and others,[12−15] and CF_3ZnX reagents developed by Wakselman[16] and Kitazume,[17] with the CF_3I/TDAE reagent being arguably inferior in some respects but superior in other respects to these alternative reagents.

Although there is some mention of the CF_3TMS reagent being diversified to allow nucleophilic "perfluoroalkylation" (that is, use of R_FTMS to carry out addition of pentafluoroethyl anion or heptafluoropropyl anion to aldehydes and ketones),[8] and there are a few papers related to similar additions of perfluoroalkyl zinc reagents,[17−19] nucleophilic perfluoroalkylation has attracted considerably less attention than the widely studied trifluoromethylation reaction, a notable exception being the important exploratory study of Petrov,[20] which will be discussed further below. We were interested to determine whether the TDAE method could be extended to be used effectively with other perfluoroalkyl iodides. In this paper, we report that the nucleophilic pentafluoroethylation reagent generated by reduction of pentafluoroethyl iodide by TDAE is almost as generally useful as the trifluoromethylation reagent, but when one tries to use

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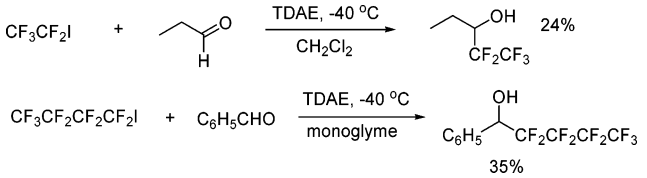
10.1021/jo060250j CCC: $33.50
Published on Web 03/29/2006

SCHEME 1



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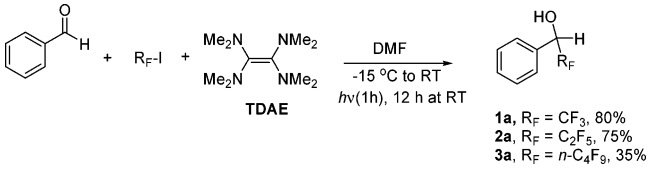


n-C_4F_9I in the reaction, yields for the most part diminish, sometimes significantly.

An early indication that TDAE might well be effective in generating synthetically useful perfluoroalkyl anions was provided in Petrov's brief study of a number of promising perfluoroalkyl anion reactions that could be instigated by TDAE (i.e, Scheme 1).[20]

Building upon these results as well as our own considerable experience with the chemistry of CF_3I/TDAE, we now wish to report the results obtained from a full study of the breadth of potential application of the use of TDAE as a reducing agent to induce nucleophilic perfluoroalkylation. A key to the success of this chemistry will be seen to be the specific use of DMF as solvent. The positive results which will be described below indicate that this technique should find much useful synthetic application for the incorporation of perfluoroalkyl groups into organic substrates. Although all of the nucleophilic *trifluoromethylation* data, including experimental details, is available within the short communications and papers referenced above, enough of these data to provide an accurate comparison will be included in the present paper.

Results and Discussion

Nucleophilic Perfluoroalkylation of Aldehydes and Ketones. As was the case for reactions with CF_3I,[1] DMF proved to be the best solvent for carrying out TDAE-induced reactions of C_2F_5I and *n*-C_4F_9I with aldehydes and ketones. When all ingredients were mixed at −15 °C, the familiar dark red color appeared. The mixture was irradiated with a sunlamp for 1 h, while warming to room temperature, and then allowed to react for 12 additional hours at ambient temperature. Light is known to often enhance the efficiency of reactions that proceed via SET (single electron transfer) processes, as does this one. In the absence of light under otherwise identical conditions, the reaction of CF_3I with 1-naphthaldehyde proceeded to give only a 69% yield, as compared to the almost quantitative reaction when the reaction was subjected to 1 h of irradiation.

Yields of pentafluoroethyl carbinols from use of C_2F_5I were comparable to those obtained when using CF_3I, but analogous reactions with perfluorobutyl iodide gave considerably lower yields (Scheme 2 and Table 1). In all cases, 2.2 equiv of both perfluoroalkyl iodide and TDAE were used per equivalent of carbonyl compound.

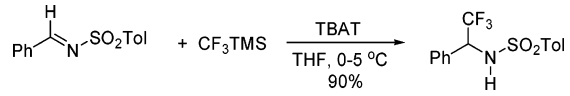
The lower yields obtained from the perfluorobutyl system may be explained by the relative instability of the red "reaction complex" obtained from *n*-C_4F_9I which loses its color more rapidly at room temperature than those obtained from both CF_3I and C_2F_5I.

TABLE 1. Perfluoroalkylation of Aldehydes and Ketones

perfluoroalkyl iodide	substrate	product	yield (%)	ref
CF_3I	benzaldehyde	**1a**	80	1
CF_3I	1-naphthaldehyde	**1b**	quant	1
CF_3I	cyclohexanone	**1c**	50	1
C_2F_5I	benzaldehyde	**2a**	75	8, 13
C_2F_5I	1-naphthaldehyde	**2b**	90	*a*
C_2F_5I	*o*-methoxycinnamaldehyde	**2c**	80	*a*
C_2F_5I	fluorenone	**2d**	95	*a*
C_2F_5I	benzophenone	**2e**	55	21
C_2F_5I	cyclohexanone	**2f**	50	8
C_2F_5I	*n*-butyraldehyde	**2g**	5	22, 23
n-C_4F_9I	benzaldehyde	**3a**	35	17
n-C_4F_9I	cyclohexanone	**3b**	20	24, 25

[a] New compound.

SCHEME 3



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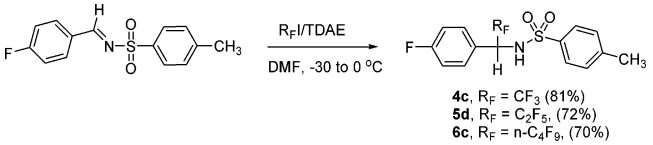

An alternative, perhaps more convenient, experimental procedure was developed for carrying out the reaction with gaseous CF_3I. In this procedure, all of the ingredients except for the CF_3I were added together and mixed at −5 °C, after which the appropriate amount of CF_3I was bubbled into the mixture while irradiating the mixture with a sun lamp. Irradiation was continued for 1 h while the mixture warmed to room temperature, and then the mixture was stirred overnight at room temperature. This procedure usually gave virtually identical yields as the former method and thus is to be preferred for its greater convenience. Only when the substrate ketone or aldehyde was itself subject to reduction by TDAE (as in the case of 1-naphthaldehyde) were the yields observed to decrease (in that case, from near quantitative to 60%).

Perfluoroalkylation of Imines. As was demonstrated by Prakash, simple alkyl- or aryl-substituted imines are relatively unreactive toward nucleophilic trifluoromethylation. However, such reactivity is enhanced significantly through the use of *N*-tosylimines (Scheme 3).[26]

Using the R_FI/TDAE methodology, trifluoromethylation[2] and pentafluoroethylation again occur with similar, high efficiencies (Scheme 4). However, in this case, the reaction with *n*-C_4F_9I also proceeds with good results, particularly when the aryl ring bears an electron-withdrawing group. Although only a 50% yield is obtained for perfluorobutylation when the aryl group is tolyl,

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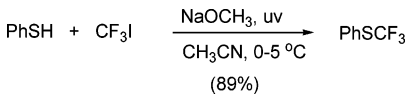
TABLE 2. Perfluoroalkylation of Tosyl Imines

R_FI	tosyl imine substrate	product	yield (%)	ref
CF_3I	benzaldehyde	**4a**	86	2
CF_3I	tolualdehyde	**4b**	84	2
CF_3I	4-fluorobenzaldehyde	**4c**	81	2
C_2F_5I	benzaldehyde	**5a**	50	*a*
C_2F_5I	*p*-tolualdehyde	**5b**	70	*a*
C_2F_5I	4-chlorobenzaldehyde	**5c**	70	*a*
C_2F_5I	4-fluorobenzaldehyde	**5d**	72	*a*
C_2F_5I	4-trifluoromethylbenzaldehyde	**5e**	68	*a*
C_2F_5I	thiophene-2- carboxaldehyde	**5f**	55	*a*
C_2F_5I	furfural	**5g**	60	*a*
C_2F_5I	*N*-methylindole-3-carboxaldehyde	**5h**	0	
n-C_4F_9I	*p*-tolualdehyde	**6a**	50	*a*
n-C_4F_9I	4-chlorobenzaldehyde	**6b**	70	*a*
n-C_4F_9I	4-fluorobenzaldehyde	**6c**	70	*a*
n-C_4F_9I	4-trifluoromethylbenzaldehyde	**6d**	75	*a*
n-C_4F_9I	thiophene-2-carboxaldehyde	**6e**	45	*a*
n-C_4F_9I	furfural	**6f**	40	*a*
n-C_4F_9I	*N*-methylindole-3-carboxaldehyde	**6g**	0	

[a] New compound.

SCHEME 5



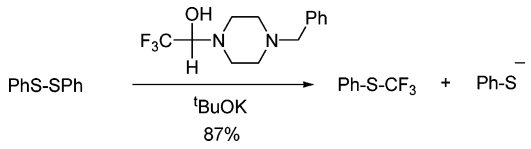
when it is 4-fluorophenyl, a 70% yield could be obtained. In all cases, 2.2 equiv of both perfluoroalkyl iodide and TDAE were used per equivalent of tosyl imine. Consistent with the greater reactivity of the electron-deficient imines, the *lack* of reactivity of the indole imine likely derives from the delocalization of the indole nitrogen's electron pair into the imine C=N bond, which would make it less electrophilic.

Because of the ease of conversion of these sulfonamide products (**4**, **5**, and **6**) to primary amines,[26] and because of the demonstrated ability to conduct such CF_3I/TDAE reactions with asymmetric induction,[2] use of the above-described nucleophilic imine perfluoroalkylation methodology should be considered anytime perfluoroalkyl-substituted primary amines are required (Table 2).

Synthesis of Perfluoroalkyl Sulfides and Selenides. Because of the potential effect of the SCF_3 group on biological activity, two important methods have been developed for the synthesis of aryl and alkyl trifluoromethyl sulfides. The first involves the $S_{RN}1$ reaction of aryl thiolates with trifluoromethyl iodide or bromide, a process first reported by Yagupolskii in 1977[27,28] and exemplified in Scheme 5. Alkanethiolates generally did not participate satisfactorily in this reaction.[29]

The other popular method involves the reaction of the trifluoromethyl anion with aryl and alkyl disulfides. There are a number of variations on this method,[30−32] and one good reaction of this type is exemplified in Scheme 6.[33] This method suffers from the fact that half of the disulfide is wasted in the process.

SCHEME 6



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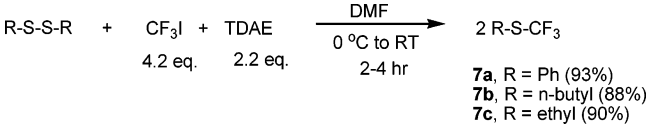

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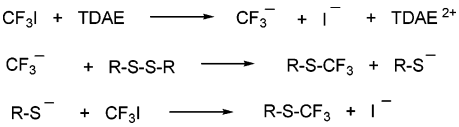

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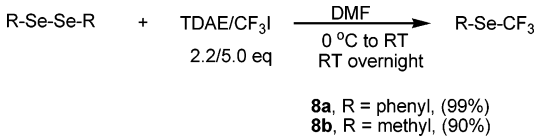

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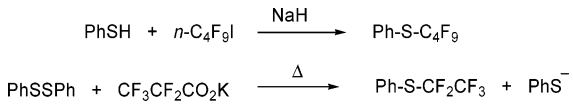

In a recent preliminary communication,[5] we reported that the reaction of the CF_3I/TDAE reagent with disulfides constituted an ideal method for the preparation of trifluoromethyl aryl and alkyl sulfides, because it effectively combined the two previous methods and thus allowed both halves of the disulfide to be utilized. Thus, when using 2.2 equiv of TDAE along with 4.4 equiv of CF_3I in a reaction with 1 equiv of a disulfide, *up to 2 equiv* of trifluoromethyl sulfide product could be formed (Scheme 7).

The proposed mechanism for this overall process is shown in Scheme 8.

It was possible to prepare seleno ethers by an analogous procedure, as shown in Scheme 9.[5]

Again, with the intent to extend this chemistry to the synthesis of perfluoroalkyl sulfides and selenides, the behavior of C_2F_5I and *n*-C_4F_9I was examined with respect to this TDAE methodology. Until now, perfluoroalkyl sulfides and selenides have been prepared by the same two methods that have been used for preparing trifluoromethyl sulfides, namely the $S_{RN}1$ method involving the reaction of aryl thiolates with perfluoroalkyl iodides[34−36] and the process of reacting perfluoroalkyl anions with aryl and alkyl disulfides (Scheme 10).[31,37]

Pentafluoroethyl iodide behaved virtually identically to CF_3I in its TDAE-induced reaction with aryl and alkyl disulfides, with a 99% yield being obtained in the reaction with phenyl disulfide (Scheme 11, Table 3).

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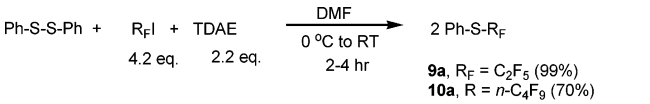
SCHEME 11



(yields based on one equiv. of disulfide)

TABLE 3. Preparation of Perfluoroalkyl Sulfides

R_FI	disulfide	R_FI (equiv)	time (h)	product	yield (%)	ref
CF_3	phenyl	5	12	**7a**	93	5, 35, 38
CF_3	butyl	5	12	**7b**	85	5, 39
CF_3	butyl	4.2	2	**7b**	85	5, 39
CF_3	ethyl	4.2	2	**7c**	90	5, 39
CF_3	4-pyridyl	5	12	**7d**	quant	5
CF_3	2-pyridyl	4.2	2	**7e**	90	5, 40
C_2F_5	phenyl	4.2	2	**9a**	99	35
C_2F_5	ethyl	4.2	2	**9b**	68	*a*[41]
C_2F_5	ethyl	4.2	4	**9b**	85	*a*[41]
C_2F_5	ethyl	4.2	12	**9b**	88	*a*[41]
C_2F_5	*n*-butyl	4.2	12	**9c**	90	*a*[41]
C_2F_5	2-pyridyl	4.2	2	**9d**	99	42
C_2F_5	4-pyridyl	4.2	2	**9e**	95	*a*
n-C_4F_9	phenyl	2.2	12	**10a**	35	34
n-C_4F_9	phenyl	4.2	12	**10a**	70	34
n-C_4F_9	ethyl	2.2	12	**10b**	20	*a*[41]
n-C_4F_9	*n*-butyl	2.2	12	**10c**	20	*a*
n-C_4F_9	*n*-butyl	4.2	12	**10c**	20	*a*
n-C_4F_9	2-pyridyl	2.2	12	**10d**	50	43
n-C_4F_9	2-pyridyl	4.2	12	**10d**	98	43
n-C_4F_9	4-pyridyl	2.2	12	**10e**	98	*a*

[a] New compound.

TABLE 4. Synthesis of Perfluoroalkyl Selenides

R_FI	diselenide	R_FI (equiv)	product	yield (%)	ref
CF_3I	phenyl	4.2	**8a**	99	38
CF_3I	methyl	4.2	**8b**	90	*a*[41]
C_2F_5I	phenyl	2.2	**11a**	49	37
C_2F_5I	phenyl	4.2	**11a**	99	37
C_2F_5I	4-chlorophenyl	4.2	**11b**	99	*a*
C_4F_9I	phenyl	2.2	**12a**	99	37
C_4F_9I	methyl	2.2	**12b**	98	*a*[41]

[a] New compound.

All three perfluoroalkyl iodides reacted equally effectively with both aryl and alkyl selenides to form the alkyl or aryl perfluoroalkyl selenides in excellent yields (Table 4).

On the basis of these results, one can conclude that in cases where it is synthetically appropriate to use disulfides or diselenides in the synthetic process, the R_FI/TDAE methodology is superior to any other procedure for making either aryl or alkyl perfluoroalkyl sulfides and selenides.

Experimental Section

Alternative Procedure for the Trifluoromethylation of Aldehydes and Ketones: 1-Phenyl-2,2,2-trifluoroethanol (1a).[1] In a 25 mL, three-neck, round-bottom flask equipped with reflux condenser and nitrogen inlet was diluted benzaldehyde (0.37 mL, 3.67 mmol) with 10 mL of anhydrous DMF. The solution was cooled to −5 °C, and TDAE (2 mL, 8.1 mmol) was added. Then CF_3I (1.6 g, 8.1 mmol) was introduced into the mixture by slowly bubbling a preweighed amount from a small cylinder into the reaction mixture via an inlet tube with its outlet being below the surface of the solution. The reaction mixture gradually turned deep red as the CF_3I was added, and a white precipitate was formed after a few minutes. The reaction mixture was irradiated by a sun lamp (UV) (GE Model RSK-6, with a 275W 110−125VAC lamp) for 1 h while the solution was maintained under 0 °C for 30 min and then was allowed to warm slowly to room temperature. The reaction mixture was then stirred at room temperature for 8 h, after which time the orange solution was filtered and the solid residue washed with diethyl ether. The DMF solution was hydrolyzed with water and was extracted with ether (three times). The combined ether layers were washed with brine and then dried over $MgSO_4$. The solvent was removed and the crude product was purified by silica gel chromatography (CH_2Cl_2/hexanes = 8:2) to give 1-phenyl-2,2,2-trifluoroethanol (**1a**)[1] in a yield of 78%.

General Procedure for Pentafluoroethylation of Aldehydes and Ketones: 1-Phenyl-2,2,3,3,3-pentafluoropropan-1-ol (2a).[8,13] Using a procedure similar to that above, benzaldehyde (0.37 mL, 3.68 mmol) and C_2F_5I (2.0 g, 8.1 mmol) in 10 mL of anhydrous DMF underwent reaction with TDAE (2 mL, 8.1 mmol) to give a crude product, which was purified by silica gel chromatography to afford **2a** as a colorless liquid in 90% yield:[8,13] ^{1}H NMR δ 7.45−7.70 (m, 5H), 5.06 (m, 1H), 2.87 (s, 1H) ppm; ^{19}F NMR δ −81.90 (m, 3F), −122.80 (m, 1F), −129.50 (m, 1F) ppm.

1-Naphthyl-2,2,3,3,3-pentafluoropropan-1-ol (2b): ^{1}H NMR δ 8.05 (d, J = 8.4 Hz, 1H), 8.0−7.82 m, 3H), 7.65−7.32 (m, 3H), 5.89 (m, 1H), 2.85 (s, 1H); ^{19}F NMR δ −81.54 (m, 3F), −118.15 (dd, J_1 = 290.4 Hz, J_2 = 20.7 Hz, 1F), −130.24 (dd, J_1 = 290.4 Hz, J_2 = 20.7 Hz, 1F). Anal. Calcd for $C_{13}H_8F_5O$: C, 56.73; H, 2.91; N, 0.0. Found: C, 56.66; H, 2.92; N, 0.0.

9-Pentafluoroethylfluoren-9-ol (2d): ^{1}H NMR δ 7.67 (m, 4H), 7.48 (m, 2H), 7.36 (m, 2H), 3.01 (s, 1H); ^{19}F NMR δ −78.62 (s, 3F), −121.29 (s, 2F). Anal. Calcd for $C_{15}H_9F_5O$: C, 60.00; H, 3.00; N, 0.0. Found: C, 60.15; H, 3.23; N, 0.0.

General Procedure for Perfluorobutylation of Aldehydes and Ketones: 1-Phenyl-2,2,3,3,4,4,5,5,5-nonafluoropentan-1-ol (3a).[17] Using an analogous procedure, n-C_4F_9I (0.75 mL, 8.1 mmol) was introduced via a syringe into a solution of benzaldehyde (0.37 mL, 3.68 mmol) in 10 mL of anhydrous DMF and the resulting solution allowed to react with TDAE (2 mL, 8.1 mmol) to give a crude product that was purified by silica gel chromatography to obtain a 30% yield of the desired alcohol (**3a**), which had ^{1}H and ^{19}F NMR spectra that were identical to those reported in the literature.[17]

1-Perfluoro-*n*-butylcyclohexanol (3b) was prepared in the same manner, and its proton and fluorine NMR spectra were also identical to those previously reported.[24,25]

General Procedure for Pentafluoroethylation of Tosyl Imines. Methyl-*N*-(3,3,3,2,2-pentafluoro-1-phenyl-propyl)-benzenesulfonamide (5a). Using a reaction procedure that was analogous to that above, *except that irradiation was not used*, *N*-(benzylidene)-*p*-methylbenzenesulfonamide (0.259 g, 1 mmol) and pentafluoroethyl iodide (0.6 g, 2.4 mmol) in 6 mL of anhydrous DMF were allowed to react with TDAE (0.51 mL, 2.2 mmol). After being stirred at room temperature overnight, about 15 mL of 10% aqueous H_2SO_4 was added slowly to quench the reaction. As the acid solution was added, the reaction mixture first became clear with the TDAE salt dissolving in water. However, the mixture then became cloudy again as the product precipitated out. The solution was allowed to stir for a while as additional product precipitated. The solid product was collected via filtration and dissolved in 30 mL of ether. This ether solution was washed 3 times with water to remove remaining DMF, the ether dried over anhydrous $MgSO_4$, and then the solvent was removed by vacuum. The pale yellow, crude product (**5a**) was recrystallized from toluene to afford 0.189 g of a white solid (50%): mp 169−170 °C; ^{1}H NMR δ 7.52 (d, J = 8.4 Hz, 2H), 7.24 (m, 3H), 7.10 (m, 4H), 5.48 (d, J = 9.9 Hz, 1H), 4.97 (m, 1H), 2.33 (s, 3H); ^{19}F NMR δ −81.42 (s, 3F), −120.67 (dd, J_1 = 291.9 Hz, J_2 = 12.9 Hz, 1F), −122.86 (dd, J_1 = 291.6 Hz, J_2 = 12.6 Hz, 1F). Anal. Calcd for $C_{16}H_{14}F_8NO_2S$: C, 50.670; H, 2.694; N, 3.694. Found: C, 50.390; H, 3.591; N, 3.590.

4-Methyl-*N*-[3,3,3,2,2-pentafluoro(4-methylphenyl)propyl]-benzenesulfonamide (5b): white solid (70% yield); mp 158−159 °C; ^{1}H NMR δ 7.52 (d, J = 8.1 Hz, 2H), 7.09 (d, J = 8.1 Hz, 2H),

7.02 (d, J = 8.4 Hz, 2H), 6.98 (d, J = 8.7 Hz, 2H), 5.50 (d, J = 9.9 Hz, 1H), 4.92 (m, 1H), 2.34 (s, 3H), 2.29 (m, 3H); ^{19}F NMR δ −81.42 (s, 3F), −120.72 (dd, J_1 = 291.6 Hz, J_2 = 12.6 Hz, 1F), −122.78 (dd, J_1 = 291.6 Hz, J_2 = 12.6 Hz, 1F). Anal. Calcd for $C_{17}H_{16}F_5NO_2S$: C, 51.91; H, 4.07; N, 3.56. Found: C, 51.72; H, 4.02; N, 3.50.

4-Methyl-*N*-[3,3,3,2,2-pentafluoro(4-chlorophenyl)propyl]-benzenesulfonamide (5c): white solid (70% yield); mp 168−169 °C; ^{1}H NMR δ 7.51 (d, J = 8.4 Hz, 2H), 7.21 (d, J = 8.4 Hz, 2H), 7.13 (d, J = 8.4 Hz, 2H), 7.05 (d, J = 8.4 Hz, 2H), 5.24 (d, J = 9.3 Hz, 1H), 4.98 (m, 1H), 2.38 (s, 3H); ^{19}F NMR δ −81.39 (s, 3H), −120.35 (dd, J_1 = 293.7 Hz, J_2 = 13.5 Hz, 1F), −123.33 (dd, J_1 = 293.7 Hz, J_2 = 13.5 Hz, 1F). Anal. Calcd for $C_{16}H_{13}ClF_5NO_2S$: C, 46.40; H, 3.141; N, 3.38. Found: C, 46.26; H, 3.12; N, 3.36.

General Procedure for Perfluorobutylation of Tosyl Imines: 4-Methyl-*N*-[5,5,5,4,4,3,3,2,2-nonafluoro(4-methylphenyl)propyl]-benzenesulfonamide (6a). In a manner similar to that used for the pentafluoroethylation reaction, *N*-(4-methylbenzylidene)-*p*-methylbenzenesulfonamide (0.273 g, 1 mmol) and nonafluorobutyl iodide (0.38 mL, 2.2 mmol) in 6 mL of anhydrous DMF were allowed to react with TDAE (0.51 mL, 2.2 mmol). In this case, a dark brown oil separated during the acidification process, and the solution was stirred for several additional hours as more brown, viscous oil was formed. Ether (30 mL) was added to dissolve the oil, the two phases were separated, and the ether solution was washed 3 times with water to eliminate remaining DMF. The ether phase was then dried over anhydrous $MgSO_4$ and the solvent removed by vacuum. The pale yellow, crude product (**6a**) was recrystallized from toluene to afford 0.189 g of a white solid (50%): mp 148−149 °C; ^{1}H NMR δ 7.51 (d, J = 8.4 Hz, 2H), 7.09 (d, J = 8.1 Hz, 2H), 7.00 (m, 4H), 5.33 (d, J = 9.9 Hz, 1H), 5.04 (m, 1H), 2.34 (s, 3H), 2.29 (s, 3H); ^{19}F NMR δ −81.4 (t, J = 9.9, 3F), −117.0 (dm, J_1 = 301.5 Hz,, 1F), −118.9 (dm, J_1 = 301.5 Hz, 1F), −121.5 (m, 2F), 126.5 (m, 2F). Anal. Calcd for $C_{19}H_{16}F_9NO_2S$: C, 46.21; H, 3.24; N, 2.84. Found: C, 46.24; H, 3.19; N, 2.82.

4-Methyl-*N*-[5,5,5,4,4,3,3,2,2-nonafluoro-(4-chlorophenyl)propyl]benzenesulfonamide (6b): white solid (70% yield); mp 140−141 °C; ^{1}H NMR δ 7.50 (d, J = 8.4 Hz, 2H), 7.18 (d, J = 8.7 Hz, 2H), 7.11 (d, J = 7.8 Hz, 2H), 7.04 (d, J = 8.4 Hz, 2H), 5.60 (d, J = 9.9 Hz, 1H), 5.07 (m, 1H), 2.37 (s, 3H); ^{19}F NMR δ −81.4 (t, J = 11.1 Hz, 3F), −116.5 (dm, J_1 = 304.8 Hz, 1F), −119.4 (d, J_1 = 304.8 Hz, 1F), −121.4 (m, 2F), 126.55 (m, 2F). Anal. Calcd for $C_{18}H_{13}ClF_9NO_2S$: C, 42.04; H, 2.53; N, 2.72. Found: C, 41.90; H, 2.46; N, 2.69.

General Procedure of the Synthesis of the Trifluoromethyl Sulfides: Phenyl Trifluoromethyl Sulfide (7a).[5,35,38] To the usual 25 mL, three-neck, round-bottom flask arrangement were added diphenyl disulfide (0.8 g, 3.68 mmol) and 10 mL of anhydrous DMF, and the solution was cooled to −5 °C at which time TDAE (2 mL, 8.1 mmol) was added. Then CF_3I (3.6 g, 18.4 mmol) was introduced to the mixture in the usual manner, *with no irradiation required*, upon which the reaction mixture became increasingly dark orange, with a white precipitate forming after few minutes. The reaction mixture was kept under 0 °C for about 30 min and was then allowed to warm slowly to the room temperature. The reaction mixture was then stirred at room temperature for 2 h, after which the orange solution was filtered and the solid washed with diethyl ether. The DMF solution was then hydrolyzed with water and was extracted with ether (3 times). The combined ether layers were washed with brine and dried over $MgSO_4$. The solvent was removed and the crude product was purified by silica gel chromatography (CH_2Cl_2/hexanes = 1:9) to give phenyl trifluoromethyl sulfide (**7a**) in a yield of 89%:[5,35,38] ^{1}H NMR δ 7.60−7.19 (m, 5H); ^{19}F NMR δ −43.20 (s, 3F).

Butyl trifluoromethyl sulfide (7b):[5,39] ^{1}H NMR δ 2.69 (t, J = 7.3 Hz, 2H), 1.66 (quintet, J = 7.4 Hz, 2H), 1.42 (sextet, J = 7.4 Hz, 2H), 0.92 (t, J = 7.4 Hz, 3H); ^{19}F NMR δ −41.50 (s, 3F).

General Synthesis of Pentafluoroethyl Thio- and Seleno-ethers: Phenyl Pentafluoroethyl Sulfide (9a). Using a procedure identical to that above, diphenyl disulfide (0.8 g, 3.68 mmol) and pentafluoroethyl iodide (3.8 g, 15.45 mmol) in 10 mL of anhydrous DMF were allowed to react with TDAE (2 mL, 8.1 mmol), after which the crude product was purified by silica gel chromatography (CH_2Cl_2/hexanes = 1:9) to give phenyl pentafluoroethyl sulfide (**9a**) in a yield of 99%:[35] ^{19}F NMR δ −83.0 (t, J_{FF} = 3.1 Hz, 3F), −92.3 (q, J_{FF} = 3.1 Hz,2F).

4-Pyridyl Pentafluoroethyl Sulfide (9e): ^{1}H NMR δ 8.51 (dd, J_1 = 4.8 Hz, J_2 = 2.0 Hz, 2H), 7.37 (dd, J_1 = 4.7 Hz, J_2 = 1.75 Hz, 2H); ^{19}F NMR δ −82.95 (t, J_{FF} = 2.14 Hz, 3F), −90.8 (q, J_{FF} = 2.14 Hz, 2F). Anal. Calcd for $C_7H_4F_5NS$: C, 36.68; H, 1.75; N, 6.11. Found: C, 36.70; H, 1.80; N, 6.21.

Phenyl pentafluoroethyl selenide (11a):[37] ^{19}F NMR δ −84.7 (t, J_{FF} = 3.2 Hz, 3F), −92.1 (q, J_{FF} = 3.2 Hz, 2F).

4-Chlorophenyl pentafluoroethyl selenide (11b): ^{1}H NMR δ 7.39 (d, J = 8.1 Hz, 2H), 7.27 (d, J = 8.1 Hz, 2H); ^{19}F NMR δ −84.7 (t, J_{FF} = 3.2 Hz, 3F), −92.1 (q, J_{FF} = 3.2 Hz, 2F). Anal. Calcd for $C_8H_4ClF_5Se$: C, 31.02; H, 1.29; N, 0.0. Found: C, 31.12; H, 1.32; N, 0.0.

General Synthesis of Nonafluorobutyl Thio- and Seleno-ethers: Phenyl Nonafluorobutyl Sulfide (10a).[34] Using a procedure identical to the previous one, diphenyl disulfide (0.8 g, 3.68 mmol) and nonafluorobutyl iodide (1.4 mL, 15.45 mmol) in 10 mL of anhydrous DMF were allowed to react with TDAE (2 mL, 8.1 mmol), and the crude product was purified by silica gel chromatography (CH_2Cl_2/hexanes = 1:9) to give phenyl nonafluorobutyl sulfide (**10a**) in the yield of 70%. The properties of this product were consistent with those reported in the literature:[34] ^{19}F NMR δ −81.3 (t, J_{FF} = 10.2 Hz, 3F), −87.4 (m, 2F), −120.5 (m, 2F), −125.9 (m, 2F).

Butyl nonafluorobutyl sulfide (10c): ^{1}H NMR δ 2.69 (t, J = 7.3 Hz, 2H), 1.66 (quintet, J = 7.6 Hz, 2H), 1.42 (sextuplet, J = 7.6 Hz, 2H), 0.93 (t, J = 7.3 Hz, 3H); ^{19}F NMR δ −81.35 (t, J_{FF} = 8.5 Hz, 3F), −87.7 (m, 2F), −121.0 (m, 2F), −125.5 (m, 2F). Anal. Calcd for $C_8H_9F_9S$: C, 31.17; H, 2.92; N, 0.0. Found: C, 31.11; H, 2.88; N, 0.0.

Phenyl nonafluorobutyl selenide (12a):[37] ^{19}F NMR δ −81.5 (t, J_{FF} = 10.7 Hz, 3F), −87.3 (m, 2F), −119.1 (m, 2F), −126.05 (m, 2F).

Phenyl trifluoromethyl selenide (8a):[38] ^{1}H NMR δ 7.60−7.26 (5H, m); ^{19}F NMR δ = −36.6 (3F, s).

Acknowledgment. Support of this work in part by the National Science Foundation is acknowledged with thanks. We also thank Dr. Viacheslav Petrov and Dr. Bruce Smart of DuPont for a generous sample of C_2F_5I and Dr. Wei Xu for obtaining the melting points of all of the imine adducts.

Supporting Information Available: General experimental methods and characterization data for compounds **2c**,**e**,**f**,**g**; **5d**−**g**; **6c**−**f**; **7c**−**e**; **9b**−**d**; **10b**,**d**,**e**; **12b**; and **8b**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO060250J

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