Study of Unusually High Rotational Barriers about S−N Bonds in Nonafluorobutane-1-sulfonamides: The Electronic Nature of the Torsional Effect

by **Ilya M. Lyapkalo***, **Hans-Ulrich Reissig**, **Andreas Schäfer**, and **Armin Wagner**

Freie Universität Berlin, Institut für Chemie, Takustr. 3, D-14195 Berlin

Dedicated to Professor *Dieter Seebach* on the occasion of his 65th birthday

Slow rotation about the S−N bond in *N,N*-disubstituted nonafluorobutane-1-sulfonamides **1** can easily be detected by NMR measurements at room temperature. This effect causes magnetic nonequivalence of otherwise identical *geminal* substituents in symmetrical staggered ground-state conformation **A**. The torsional barriers determined (62–71 kJ · mol^{-1}) proved to be the highest ever observed for sulfonamide moieties. They are comparable to the values routinely measured for carboxylic acid amides or carbamates. The restricted rotation is interpreted as result (n_N-d_S)-π and of $n_N-\sigma^*_{S,C}$ interactions, which develop substantial S,N double-bond character in sulfonamides **1**. The S,N binding interaction is increased by the highly electron-withdrawing effect of the perfluorobutyl group. The anticipated symmetry of the ground-state conformation **A** and the considerable shortening of the S−N bond (1.59 Å) compared to the mean value in sulfonamides (1.63 Å) are confirmed by single-crystal X-ray study of *N,N*-dibenzylnonafluorobutane-1-sulfonamide (**1c**).

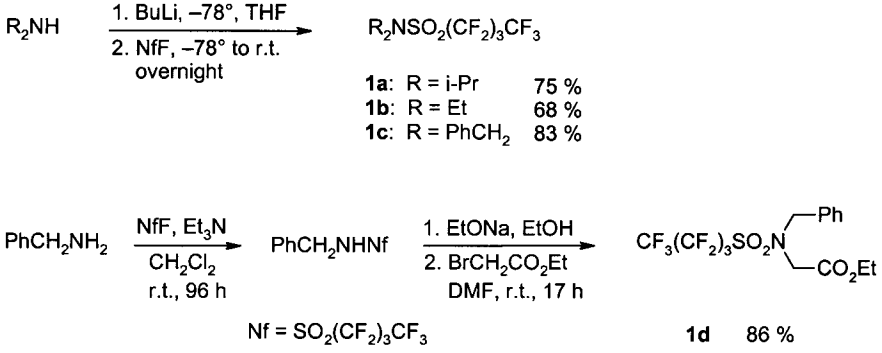
Restricted rotation [1] is a well-known phenomenon for compounds **I** with single bonds Y−A that adopt considerable double-bond character due to the binding interactions of the electron-withdrawing π-system X=Y with the lone pair at A, as expressed by the dipolar mesomeric formula **II** (*Scheme 1*). This has been described for Y and A elements of the second row of the periodic table. Not surprisingly, the highest values of barriers to rotation are normally observed for compounds containing an amino group (A = N), due to the very strong π-donating character of the N-atom. Hindered rotation of this type is well-documented, and the barriers to rotation have been measured for many classes of compounds [1][2], including esters, nitrites, enamines, hydrazones, thio- and selenoamides, nitrosoamines, and triazenes [3]. Undoubtedly, carbamates and amides proved to be the most frequently occurring substances exhibiting atropisomerism about their C−N bonds. Reviews on dynamic effects in amides and related compounds [2][4] reflect the fundamental character and significance of this topic. Elements of the third (*e.g.*, Si, P, S) and higher periods exhibit much lower tendencies to π-bond. As a consequence, the barriers to rotation in the

Scheme 1

respective acid amides, *e.g.*, in sulfonamides[1]) are expected to be much lower than those of carboxylic acid amides. In this publication, we describe for the first time representatives of sulfonamides[2]) with surprisingly high barriers to rotation about the S–N bonds, similar to those reported for carboxylic acid amides [1][2] or carbamates [7][8].

Because of our interest in the synthesis and application of alkenyl *nonafl*uoro- (*i.e.*, perfluoro-) butane-1-sulfon*ates* (nonaflates) in Pd-catalyzed C,C cross-coupling reactions [9], we prepared several alkenyl nonaflates from ketones with a small excess of lithium diisopropylamine as a base to ensure complete deprotonation. The subsequent treatment of the mixtures with nonafluorobutane-1-sulfonyl fluoride (NfF) resulted in formation of the desired alkenyl nonaflates along with a side product, which was identified by MS, IR, and microanalysis data as *N*,*N*-diisopropylnonafluorobutane-1-sulfonamide (**1a**). The structure of **1a** was further confirmed by independent synthesis from lithium diisopropylamine and NfF, as shown in *Scheme 2*.

Scheme 2. *Synthesis of* N,N-*Disubstituted Nonafluorobutane-1-sulfonamides* **1**



^{1}H- and ^{13}C-NMR spectra of *N*,*N*-diisopropylnonafluorobutane-1-sulfonamide (**1a**) show two magnetically nonequivalent Me groups at ambient temperature (*Fig. 1*). At elevated temperature, the signals collapse to one. However, the two i-Pr groups exhibit a single CH-signal, which remains almost intact over this temperature interval. This

---

1) The ^{1}H-NMR spectra of $PhSO_2NEt_2$, $MeSO_2NEt_2$, $(Et_2N)_2SO_2$ remained unchanged as a function of temperature down to $-90°$ [5], hence the barriers to rotation are not higher than 35 kJ·mol^{-1}.

2) To the best of our knowledge, chlorosulfonyl amides $ClSO_2NR_2$ (R = Et, i-PrCH_2, PhCH_2) are the only representatives of sulfonamides whose restricted amide rotation has been described at low temperature [5], and the barriers have been found to be in the range of 46–48 kJ·mol^{-1}, considerably lower than the respective values for nonafluorobutane-1-sulfonamides reported herein. A sulfonamide torsional barrier of 43.5 ± 0.5 kJ·mol^{-1} has also been reported for *N*,*N*′-bis(toluene-4-sulfonyl)-5,6,7,12,13,14-hexahydro-6,13-diazadibenzo[*a*,*f*]cyclodecene. However, the authors suggested steric hindrance at the transition state to be the most-important contribution to the rotation barrier [6].

observation could be interpreted as hindered rotation about the S–N bond[3]), the ground-state conformation **A** being as depicted in *Fig. 1*. This conformation is generally favored for sulfonamides [5] as evidenced from extensive X-ray data in the literature (*e.g.*, [6][11]).

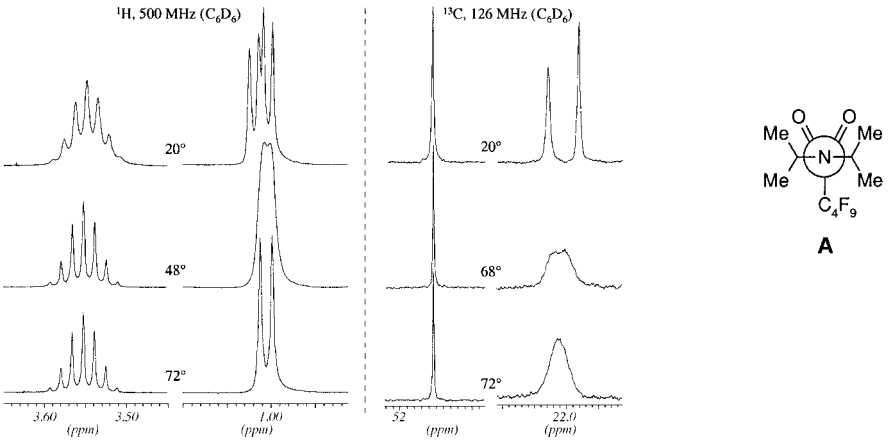


Fig. 1. *Dynamic ^{1}H- and ^{13}C-NMR spectra of* N,N-*diisopropylnonafluorobutane-1-sulfonamide* (**1a**). High-temperature process, corresponding to slow rotation about S–N bond; ground-state staggered conformation **A**.

At low temperature (down to $-93°$), we observed a second dynamic process that resulted in the appearance of six different signals (four Me and two CH) corresponding to two i-Pr groups in ^{1}H- and ^{13}C-NMR and splitting of all CF_2 groups to *AB* systems in ^{19}F-NMR (*Fig. 2*). The free energy (ΔG) of activation was 40 kJ · mol^{-1}. This process can be attributed to hindered rotation of i-Pr groups about CH–N bonds. Torsional effects in various geminal diisopropyl systems have been studied in detail by experiment and theory [12].

We decided to study hindered rotation about the S–N bond in *N,N*-disubstituted perfluorobutane-1-sulfonamides **1** in more detail to verify the generality of this process and to determine the energy parameters of the torsional barriers. By analogy to synthesis of **1a**, **1b**, and **1c** were prepared from the corresponding amines *via* lithiation followed by sulfonylation with NfF. Unsymmetrical sulfonamide **1d** was synthesized in two steps starting from benzylamine (*Scheme 2*). As expected, ^{1}H-NMR spectra of compounds **1b**–**d** at room temperature show nonequivalence of diastereotopic CH_2 protons (*AB* system) with the typical geminal coupling values J_{AB} (*Table*). The barriers to rotation about the S–N bond for **1a**–**d** determined by total line shape analyses of the NMR signals [13] are collected in the *Table*.

---

[3]) Alternatively, the observed dynamic effect could result from slow inversion of the pyramidal N-atom in **1a**, typically known for amines possessing electronegative substituents (RO, F, Cl) at N and particularly for aziridines. However, we can safely rule out the slow inversion effect in sulfonamides because sulfonyl substituents are known to flatten pyramidal N-atoms, resulting in a decrease of the inversion barrier in *N*-sulfonylaziridines [10]; furthermore, single-crystal X-ray data ([6][11], *Fig. 3*) clearly indicate an almost planar trigonal N-atom in sulfonamides.

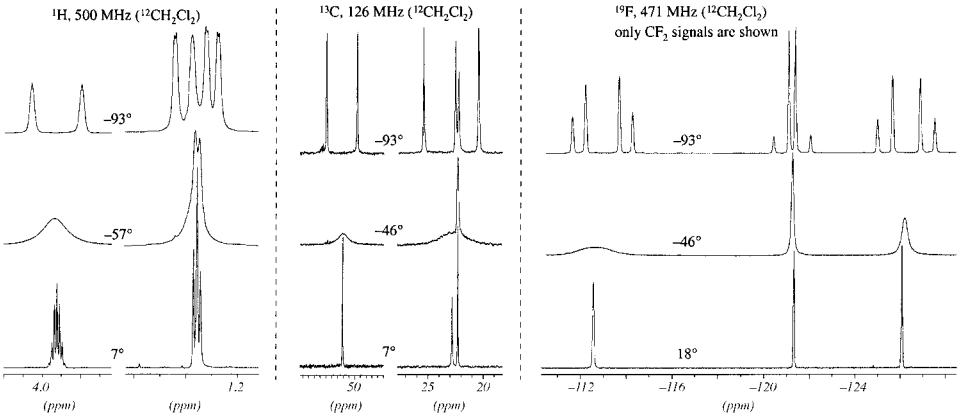


Fig. 2. *Low-temperature process, most likely corresponding to slow rotation of the sterically interacting i-Pr groups in* **1a**

Table. *Geminal-Coupling-Constant Values and Barriers to Rotation about S–N Bond for Nonafluorobutane-1-sulfonamides* **1a–d**

Sulfonamide	J_{AB} [Hz][a])	$\Delta G^{\neq}_{298}$ [kJ · mol^{-1}][a])
1a	–	70.0 ± 2.3 70.5 ± 2.0 (in C_6D_6) 42.4 ± 3.6[b])
1b	14.6	64.4 ± 2.8
1c	15.2	62.4 ± 3.6
1d	14.9 (PhCH_2) 18.5 (CH_2CO_2Et) 12.0 (MeCH_2O)	64.4 ± 6.6

[a]) In $CDCl_3$ (500 MHz) unless otherwise noted. [b]) Presumably, hindered isopropyl rotation (see text).

Evidently, the values obtained are comparable to those routinely determined for carboxylic acid amides (*e.g.*, $MeC(O)NMe_2$ 72 kJ · mol^{-1} [4]); $MeC(O)N(i\text{-}Pr)_2$ [1] 68 kJ · mol^{-1}; $PhCH_2OC(O)NMe_2$ [8] 66 kJ · mol^{-1}). These amides are known to possess planar or almost planar structures with the C–N bond adopting a considerable double-bond character. We expected a similar effect for the sulfonamides **1** and, therefore, were interested to obtain exact structural parameters by single-crystal X-ray analysis of *N*,*N*-dibenzylnonafluorobutane-1-sulfonamide (**1c**) (*Fig. 3*).

The $(Ph-CH_2-)_2N-S(=O)_2-C(1)$ fragment adopts an almost perfectly symmetrical staggered conformation with a trigonal planar N-atom, as was suggested for **1a** (see *Fig. 1*). Phenyl rings are arranged in two almost parallel planes in the direction opposite to the perfluorinated butyl chain. This conformation creates minimum crowding around the S–N bond, which suggests that electronic and not steric effects

[4]) This value was determined in benzene; for the influence of the medium on the barrier to rotation in amides, see [14].

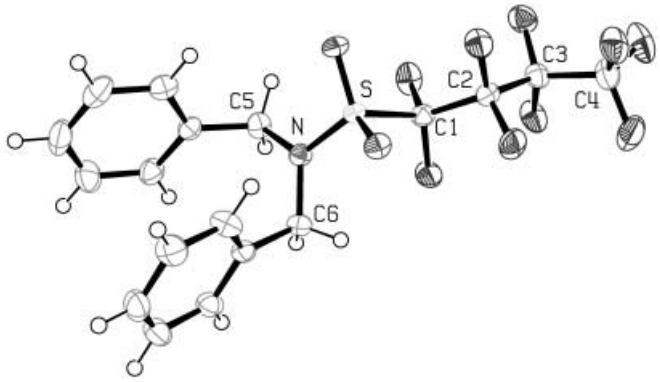


Fig. 3. *ORTEP View of the crystal structure of* N,N-*dibenzylnonafluorobutane-1-sulfonamide* (**1c**) *showing the arrangement of substituents around the S–N bond*. For details, see text and *Exper. Part*.

are responsible for the observed restricted rotation[5]). Indeed, the S–N bond (1.589(2) Å)[6]) seems to exhibit appreciable double-bond character: it is considerably shorter than the mean value for sulfonamides (1.63(2) Å)[7]).

The comparison of the influence of the electron-withdrawing perfluorinated substituent on the barrier to rotation in sulfonamides *vs.* carboxylic acid amides is most interesting. While formal exchange of the Ph or Me substituent at the S-atom of sulfonamides by perfluorobutyl results in an increase of the barrier to rotation by at least 30 kJ · mol^{-1}[1]), the introduction of a CF_3 substituent instead of Me has almost no effect on the free energy of activation in carboxylic acid amides (*e.g.*, $CF_3C(O)NMe_2$ 76 kJ · mol^{-1}; $CF_3C(O)N(i\text{-}Pr)_2$ 68 kJ · mol^{-1}, *cf.* the values for the corresponding acetamides given above)[8]). The values for trifluoroacetamides apparently are the result of two opposing effects. On the one hand, the highly electron-withdrawing effect of the CF_3 group favors the dipolar resonance formula with C=N, in which the positive charge is maximally transferred from the carbonyl C-atom to the N-atom. On the other hand, steric demands destabilize the planar dipolar ground state, in which steric repulsion between the relatively bulky CF_3 and *cis*-alkyl group is unavoidable[8])[9]). This implies that the opposing electronic and steric effects result in little or no apparent influence on the barrier to rotation in this particular case[10]).

---

[5]) Certainly, we realize that a conformation in solution may considerably differ from that in the crystal. Nevertheless, we regard the observed effect as due to a π-binding interaction because no torsional effects could be deduced from ^{1}H-NMR spectra of sterically demanding compounds such as 2-methyl-2-propane- [15], 2,4,6-trimethyl-1-benzene- [16], or even 2,4,6-triisopropyl-1-benzenesulfonamides [17]. The steric demand of i-Pr substituents may give a small contribution to the slightly higher free activation energy in the sulfonamide **1a** compared to **1b–d**.

[6]) It is slightly longer than the genuine S=N of arylsulfonimidoyl amides (1.52–1.55 Å) [18].

[7]) The mean value has been obtained from the respective search in the *Cambridge Structural Database* which gave 272 S–N bond lengths for *N,N*-disubstituted sulfonamides.

[8]) In *N,N*-disubstituted amides, the barrier to rotation decreases upon increase of steric demand of the carbonyl substituent [1].

[9]) For a detailed discussion of effects in *N,N*-dialkyl trifluoroacetamides, see [19].

[10]) Switching to the acetyl substituent, which is sterically less-demanding than CF_3, results in substantial increase of the barrier to rotation in $MeC(O)C(O)NMe_2$ (86.1 kJ · mol^{-1}) [20].

Unlike carboxylic acid amides, *both* the steric demands of substituents at the N-atom *and* the electron-withdrawing ability of the substituent at the S-atom should stabilize the symmetrically staggered ground-state conformation **A** (*Fig. 1*), in which a desirable (n_N-d_S)-π overlap is most efficiently attained [5]. The dynamic NMR effects for *N*,*N*-diisopropyl sulfonamides with other electronegative substituents at the S-atom were expected to be similar to those described herein for sulfonamides **1**. Surprisingly, we could not deduce hindered rotation about S–N bonds from literature NMR data of several candidates [21], *e.g.*, *N*,*N*-diisopropyl trichloromethanesulfonamide, *N*,*N*-diisopropyl 4,6-dimethylpyrimidine-2-sulfonamide, or *N*,*N*-diisopropylnitromethanesulfonamide. Furthermore, none of numerous *N*,*N*-dialkyl trifluoromethanesulfonamides have been found to exhibit hindered S,N rotation at ambient temperature [22]. Notably, the ^{1}H-NMR spectra of *N*-perchloryl-*N*,*N*-dialkylamines reported in the literature [23] indicate a broadening or a multiplicity of NCH_2 groups that may result from the torsional effect related to that found for sulfonamides **1**.

We assume that the S–N double-bond character is a result of (n_N-d_S)-π overlap[11]) along with considerable contribution of the $n_N-\sigma^*_{S,C}$ binding interaction, which accounts for the observed exceptionally high rotational barriers in perfluorobutane-1-sulfonamides. This negative hyperconjugative effect is well-known to assist the stabilization of S- and Se-substituted carbanions, the effect being subject to stereoelectronic control [24]. Furthermore, it is evident that the symmetrically staggered conformation **A** (see *Fig. 1*) is optimal for this kind of interaction, since the lone pair at the N-atom is disposed in the same plane as the S–C bond. Finally, the energy of the $\sigma^*_{S,C}$ orbital is strongly reduced by the highly electron-withdrawing perfluorinated substituent in sulfonamides **1a**–**d**, thereby facilitating the $n_N-\sigma^*_{S,C}$ overlap[12])[13]). We believe that appropriate calculations will allow estimation of the electronic contribution to the observed slow rotation.

The notable difference in spectral appearances between the sulfonamides **1a**–**d** and trifluoromethanesulfonamides [22] remains to be rationalized. Since the electronic effects described above would also operate in the trifluoromethyl derivative, the difference might be a consequence of the stronger electron-withdrawing effect of the perfluorobutyl substituent compared to trifluoromethyl. This results in better leaving-group ability of a nonaflate compared to a triflate [26], although the difference is usually moderate to low.

Alternatively, an extended negative hyperconjugative effect with $n_N-\sigma^*_{S,C}-\sigma^*_{S,C(F)}$ overlap (*Fig. 4*) could account for the observed differences between the perfluorinated substituents[14]). As evidenced from the X-ray structure of **1c** (see *Fig. 3*), the dihedral

---

[11]) A stabilization of the negative charge of α-deprotonated sulfones, which are isoelectronic to sulfonamides, is achieved by overlap with d-orbitals of the SO_2 S-atom [24].

[12]) Obviously, the geometry of the planar ground-state conformation of carboxylic acid amides, in which the lone pair of the N-atom and the C–C bond adjacent to the carbonyl group are arranged in the perpendicular planes, *a priori* excludes simultaneous $(n_N-p_{C=O})$-π and $n_N-\sigma^*_{C,C}$ overlap.

[13]) A remarkably fast intermolecular halogen exchange in *N*,*N*-dialkyl halogeno-sulfinylamides could be rationalized in terms of strong $n_N-\sigma^*_{S,X}$ interaction leading to the equilibrium by dissociation: $R_2NS(O)X \rightleftharpoons [R_2N{=}S{=}O]^+ X^-$ [25].

[14]) To our surprise, no slow rotation about the S–N bond could be concluded from the NMR data available of a few other poly- and perfluorinated sulfonamides described in the literature [27], *e.g.*, $Cl(CF_2)_2O(CF_2)_2$-$SO_2N(CH_2Ph)_2$ or *N*,*N*-diethylperfluorooctane-1-sulfonamide.

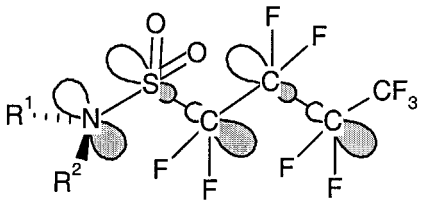


Fig. 4. *Schematic representation of the extended* $n_N - \sigma^*_{S,C} - \sigma^*_{C,C(F)}$ *overlap in nonafluorobutane-1-sulfonamides* **1**

angle S–C(1)–C(2)–C(3) has a value of 161°, which is rather close to the optimal 180° for this kind of interaction[15]). On the other hand, the effect should be rather subtle since it does not affect C–C bond lengths in the perfluorinated butyl chain of **1c**.

Conclusion. – We described herein unusually slow rotation about the S–N bond in sulfonamides, easily detectable at ambient temperature by NMR. The determined barriers to rotation in nonafluorobutane-1-sulfonamides **1** proved to be comparable to those well-known for carboxylic acid amides. The effect is rationalized as a result of the appreciable double-bond character adopted by the S–N bond due to $(n_N - d_S)$-π and $n_C - \sigma^*_{S,C}$ interactions that are amplified by the highly electron-withdrawing nature of the perfluorobutyl substituent. We did not try to determine the specific contribution of either of the electronic interactions to the observed atropisomerism and defer this problem to calculations remaining to be performed. Since sulfonamides are isoelectronic to α-sulfonyl carbanions, we believe that the dynamic effects described herein may improve insight into the origin of negative-charge delocalization in α-sulfur carbanions [24][29] and into the nature of π-binding of third- and higher-period elements.

Generous support by the *Deutsche Forschungsgemeinschaft*, the *Fonds der Chemischen Industrie* and the *Alexander von Humboldt Foundation* (research fellowship for *I. M. L.*) is most gratefully acknowledged. We thank *Schering AG*, Berlin for general support, *Bayer AG*, Leverkusen for generous donations of nonafluorobutane-1-sulfonyl fluoride, Mr. *B. Füger* for the synthesis of the compound **1b** and Dr. *R. Zimmer* for help during preparation of this manuscript.

Experimental Part

1. *General*. NMR Spectra: *Bruker WH-270* at 20°. Dynamic NMR measurements *Bruker AMX-500* under cooling and *Jeol Eclipse-500* under heating conditions; chemical shifts (δ) in ppm down-field from Me_4Si ($\delta = 0$) as an internal standard; coupling constant *J* in Hz. An assignment of ^{19}F signals of the $CF_3(CF_2)_3$ group is given according to [30] in ppm up-field from $CFCl_3$ ($\delta = 0$) as an internal standard; ^{13}C-NMR signals of the $CF_3(CF_2)_3$ group are not given since, due to strong splitting by coupling with the ^{19}F nuclei, unambiguous assignment is not possible. MS: *Varian MAT-711*; *m*/*z* (%). IR: *Nicolet 5 SXC*; ν in cm^{-1}. TLC: *Merck 60* F_{254} silica gel plates. Column chromatography (CC): silica gel 60 (40–63 μm, *Fluka*). Lithiation and 'nonaflation' reactions were carried out under Ar in heat-gun dried reaction flasks by adding the components *via* syringe. Solvents for reactions were dried by standard procedures. Nonafluorobutane-1-sulfonyl fluoride was obtained from *Bayer AG*; it can also be purchased from *Aldrich*. Commercially available 2.5M BuLi (*Aldrich*) was titrated by the [1,10]phenanthroline method [31].

---

[15]) A perfectly staggered conformation of perfluorinated chains in sodium bis(perfluorobutane-1-sulfonyl)-imide with 175° S–C(1)–C(2)–C(3) dihedral angle detected by single-crystal X-ray analysis might gain in stabilization from such an extended hyperconjugative effect [28].

2. *Synthesis of Perfluorobutane-1-sulfonamides* **1a**–**c**. *General Procedure* (*GP*). A soln. (2.45M) of BuLi in hexane (5.6 ml, 13.7 mmol) was added to a soln. of R_2NH (15.0 mmol) in THF (40 ml) at $-78°$. The cooling bath was removed, and the resulting mixture was allowed to warm to r.t., before recooling to $-78°$. To the thus-generated soln. of R_2NLi (13.7 mmol), neat NfF (6.06 g, 20.0 mmol) was added *via* syringe at $-90°$. The mixture was gradually warmed to 18° and stirred overnight. After aq. workup (150 ml hexane, 60 ml sat. aq. $NaHCO_3$, and 60 g ice), the aq. phase was extracted with hexane (3×30 ml), and the combined org. phases were dried (Na_2SO_4). Filtration, removal of volatile components *in vacuo* followed by distillation or CC gave the expected pure sulfonamides **1a**–**c**.

N,N-*Diisopropylperfluorobutane-1-sulfonamide* (**1a**). According to the *GP*, diisopropylamine (1.52 g, 15.0 mmol) furnished sulfonamide **1a** after bulb-to-bulb distillation at 105° (1 mbar) as a pale yellowish liquid (4.29 g, 75% yield), essentially pure according to ^{1}H- and ^{13}C-NMR. For analytical purposes, a sample of **1a** was further purified by CC (hexane) and isolated as a colorless microcrystalline material after re-condensation in high vacuum (25°/$< 5 \cdot 10^{-4}$ mbar) in a cold ($-30°$) *Schlenk* flask. It melts below r.t. to give a clear colorless liquid. IR (film): 2985–2885 (C–H), 1380 (SO_2), 1240 (C–F), 1205 (C–F), 1140 (C–F). ^{1}H-NMR (270 MHz, $CDCl_3$): 1.37 (br. *d*, $^3J = 6.8$, Me_2CHN); 1.38 (*d*, $^3J = 6.8$, Me_2CHN); 3.93 (*hept.*, $^3J = 6.8$, 2 Me_2CH). ^{13}C-NMR (67.5 MHz, $CDCl_3$): 22.1 (*q*, Me); 22.6 (*q*, Me); 51.5 (*d*, CH). ^{19}F-NMR (470.6 MHz, $CDCl_3$, 34°): -126.4 (*t**, $J = 13.9$, $CF_2(3)$); -121.6 (m_c, $CF_2(2)$); -112.8 (br. *t*, $J = 13.8$, $CF_2(1)$); -81.3 (*tt*, $J_1 = 10.0$, CF_3); * indicates further splitting due to multiple ^{19}F,^{19}F couplings. ^{19}F-NMR (470.6 MHz, $^{12}CD_2Cl_2$, $-93°$): -127.9 (br. *d*, $^2J = 292$, F–C(3)); -126.2 (br. *d*, $^2J = 292$, F–C(3)); -122.6 (br. *d*, $^2J = 303$, F–C(2)); -121.9 (br. *d*, $^2J = 303$, F–C(2)); -115.2 (br. *d*, $^2J = 261$, F–C(2)); -113.3 (br. *d*, $^2J = 261$, F–C(2)); -81.0 (br. *s*, CF_3). MS (EI, 80 eV): 383 (1, M^+), 368 (10, $[M - Me]^+$), 326 (50, $[M - i\text{-}PrN]^+$), 262 (10, $[M - i\text{-}PrN - SO_2]^+$), 242 (4, $[M - i\text{-}PrN - SO_2 - HF]^+$), 219 (9, $[CF_3(CF_2)_3]^+$), 164 (10, $[M - CF_3(CF_2)_3]^+$), 131 (3, $[CF_2{=}CFCF_2]^+$), 122 (15, $[M - CF_3(CF_2)_3 - CH_3CH{=}CH_2]$), 69 (13, CF_3^+), 43 (100, Me_2CH^+). Anal. calc. for $C_{10}H_{14}F_9NO_2S$ (383.3): C 31.34, H 3.68, N 3.65, S 8.37; found: C 31.37, H 3.59, N 3.58, S 8.16.

N,N-*Diethylperfluorobutane-1-sulfonamide* (**1b**). According to the *GP*, diethylamine (1.10 g, 15.0 mmol) furnished pure sulfonamide **1b** as a yellowish liquid after fractional distillation (3.62 g, 68% yield). B.p. 91° (8 mbar). IR (film): 2985–2905 (C–H), 1390 (SO_2), 1240 (C–F), 1215 (C–F), 1140 (SO_2). ^{1}H-NMR (500 MHz, $CDCl_3$, $-10°$): 1.28 (*t*, $^3J = 7.2$, 2 Me); 3.47 (*dq*, $^2J = 14.6$, $^3J = 7.2$, 2 CH_AH_B); 3.59 (*dq*, $^2J = 14.6$, $^3J = 7.2$, 2 CH_AH_B). ^{13}C-NMR (67.5 MHz, $CDCl_3$): 14.0 (*q*, Me), 42.9 (*t*, CH_2). ^{19}F-NMR (470.6 MHz, $CDCl_3$, 20°): -126.4 (*t**, $J = 14.1$, $CF_2(3)$); -121.8 (m_c, $CF_2(2)$); -113.4 (*t**, $J = 14.1$, $CF_2(1)$); -81.2 (*tt*, $J = 10.1$, 2.4, CF_3); * indicates further splitting due to multiple ^{19}F,^{19}F couplings. MS (EI, 80 eV): 355 (19, M^+), 340 (90, $[M - Me]^+$), 312 (5, $[M - NEt]^+$), 248 (24, $[M - NEt - SO_2]^+$), 228 (3, $[M - NEt - SO_2 - HF]^+$), 219 (22, $[CF_3(CF_2)_3]^+$), 169 (1, $[CF_3(CF_2)_2]^+$), 136 (100, $[M - CF_3(CF_2)_3]^+$), 131 (19, $[CF_2{=}CFCF_2]^+$), 120 (21, $[Et_2NS{=}O]^+$), 119 (5, $C_2F_5^+$), 108 (32, $[M - CF_3(CF_2)_3 - CH_2{=}CH_2]^+$), 100 (5, $C_2F_4^+$), 92 (9, $[EtNHS{=}O]^+$), 80 (10, $[H_2NSO_2]^+$), 72 (15, $C_4H_{10}N^+$), 71 (9, $C_4H_9N^+$), 70 (5, $[MeCH{=}N{=}CHMe]^+$), 69 (75, CF_3^+), 64 (10, $[H_2NSO]^+$ or SO_2^+), 57 (73, $[EtN{=}CH_2]^+$), 56 (67, $[MeCH{=}N{=}CH_2]^+$), 50 (2, CF_2^+), 44 (87, $C_2H_6N^+$), 42 (68, $C_2H_4N^+$), 29 (69, $C_2H_5^+$), 28 (34, $C_2H_4^+$), 27 (16, $C_2H_3^+$). HR-MS: 355.02911 (M^+, $C_8H_{10}F_9NO_2S$; calc. 355.028855), 136.04621 ($Et_2NSO_2^+$, $C_4H_{10}NO_2S$; calc. 136.043225).

N,N-*Dibenzylperfluoro-1-butanesulfonamide* (**1c**). According to the *GP*, dibenzylamine (2.96 g, 15.0 mmol) furnished pure sulfonamide **1c** after CC (gradient elution: hexane → hexane/Et_2O 30:1 → hexane/Et_2O 20:1 → hexane/Et_2O 8:1) as colorless crystals (5.97 g, 83% yield). M.p. 82–84°. IR (KBr): 3090–3035 (H–C=), 1495–1450 (C=C), 1380 (SO_2), 1250 (C–F), 1215 (C–F), 1135 (SO_2). ^{1}H-NMR (500 MHz, $CDCl_3$, 10°): 4.39 (*d*, $^2J = 15.2$, 2 CH_AH_B); 4.55 (*d*, $^2J = 15.2$, 2 CH_AH_B); 7.17–7.20 (*m*, 4 arom. H); 7.32–7.36 (*m*, 6 arom. H). ^{13}C-NMR (125.8 MHz, $CDCl_3$, 10°): 51.3 (*t*, CH_2); 128.5 (*d*, C_p); 128.7, 128.8 (br. *d*, *d*, C_o, C_m); 133.5 (*s*, C_{ipso}). ^{19}F-NMR (470.6 MHz, $CDCl_3$, 20°): -126.2 (*t**, $J = 13.9$, $CF_2(3)$); -121.4 (m_c, $CF_2(2)$); -111.8 (*t**, $J = 13.9$, $CF_2(2)$); -81.3 (*tt*, $J = 9.9$, 2.4, CF_3); * indicates further splitting due to multiple ^{19}F,^{19}F couplings. MS (EI, 80 eV): 480 (3, $[M + 1]^+$), 479 (13, M^+), 388 (4, $[M - PhCH_2]^+$), 260 (1, $[M - CF_3(CF_2)_3]^+$), 219 (1, $[CF_3(CF_2)_3]^+$), 196 (6, $[M - CF_3(CF_2)_3SO_2]^+$), 195 (6, $[PhCH_2N{=}CHPh]^+$), 194 (6, $[PhCH{=}N{=}CHPh]^+$), 182 (1, $[M - CF_3(CF_2)_3SO_2 - CH_2]^+$), 167 (1, Ph_2CH^+), 131 (1, $[CF_2{=}CFCF_2]^+$), 118 (4, $[CH_2{=}N{=}CHPh]^+$), 104 (3, $PhC{\equiv}NH^+$), 92 (85, $[PhMe]^+$), 91 (100, $[PhCH_2]^+$), 69 (4, CF_3^+). Anal. calc. for $C_{18}H_{14}F_9NO_2S$ (479.4): C 45.10, H 2.94, N 2.92; found C 45.14, H 2.81, N 2.78.

N-*Benzylperfluorobutane-1-sulfonamide*. Neat NfF (6.65 g, 22 mmol) was carefully added dropwise to a vigorously stirred soln. of benzylamine (2.36 g, 22 mmol) and Et_3N (4.76 g, 47 mmol) in CH_2Cl_2 (15 ml) at 0°. After 1 h, the temp. was allowed to rise to 20°, and the mixture was stirred for further 96 h. It was then subjected to aq. workup (150 ml Et_2O, 100 ml H_2O, 50 g ice, and 4 ml 85% H_3PO_4); the aq. phase was extracted with Et_2O (3×20 ml), the combined org. phase was washed successively with H_2O (70 ml) and brine (50 ml) and dried

($MgSO_4$). Filtration, removal of the volatile components in vacuum, and thorough drying of the residue in high vacuum at ambient temperature (0.005 mbar) for 12 h gave pure *N*-benzylperfluoro-1-butanesulfonamide (7.62 g, 89% yield) as slightly yellowish crystals, which was used in the next step without further purification. M.p. 57–60°. IR (KBr): 3310 (N–H), 3040 (H–C=), 1495–1440 (C=C), 1360 (SO_2), 1235 (C–F), 1210 (C–F), 1140 (SO_2). ^{1}H-NMR (270 MHz, $CDCl_3$): 4.47 (br. *s*, CH_2); 5.30 (br. *s*, NH); 7.30–7.45 (*m*, 5 arom. H). ^{13}C-NMR (67.5 MHz, $CDCl_3$): 48.6 (*t*, CH_2), 127.9, 129.1 (2*d*, C_o, C_m), 128.7 (*d*, C_p), 135.1 (*s*, C_{ipso}). MS (EI, 80 eV): 390 (2, $[M+1]^+$), 389 (12, M^+), 219 (<1, $[CF_3(CF_2)_3]^+$), 170 (6, $[M-CF_3(CF_2)_3]^+$), 131 (2, $[CF_2{=}CFCF_2]^+$), 119 (2, $C_2F_5^+$), 107 (3, $C_7H_9N^+$), 106 (36, $C_7H_8N^+$), 105 (25, $C_7H_7N^+$), 104 (16, PhC≡NH^+), 103 (1, $PhCN^+$), 100 (2, $C_2F_4^+$), 92 (8, $PhMe^+$), 91 (100, $PhCH_2^+$), 79 (12, $C_6H_7^+$, 78 (6, $C_6H_6^+$), 77 (12, $C_6H_5^+$), 69 (15, CF_3^+), 65 (5, HSO_2^+), 51 (8, HCF_2^+), 50 (2, CF_2^+), 39 (3, HC_2N^+ or F_2^+), 28 (20, HC≡NH^+), 27 (2, HCN^+). Anal. calc. for $C_{11}H_8F_9NO_2S$ (389.2): C 33.94, H 2.07, N 3.60; found C 33.96, H 1.85, N 3.67.

Ethyl N-*Benzyl*-N-*[(perfluorobut-1-yl)sulfonyl]aminoacetate* (**1d**). Na Metal (0.219 g, 9.53 mmol) was dissolved in abs. EtOH (10 ml), and the resulting clear, colorless soln. was cooled to 0°. To the prepared EtONa soln., *N*-benzylperfluorobutane-1-sulfonamide (3.71 g, 9.52 mmol) was added in one lot at 0°, and the mixture was gradually warmed to ambient temp. for 1 h with stirring. After all volatile components had been removed *in vacuo*, toluene was added to the residue, and the resulting suspension was vigorously stirred for 10–15 min followed by removal of toluene *in vacuo* and drying of the resulting Na salt at ambient temp. (0.005 mbar) for 2 h. The prepared *sodium* N-*benzylperfluorobutane-1-sulfonamide* (3.03 g, 7.37 mmol) was dissolved in DMF (7 ml), and neat ethyl 2-bromoacetate (1.35 g, 8.10 mmol) was added dropwise at 0°. After 2 h, the temp. was allowed to rise to 20°, and the mixture was stirred for a further 17 h. It was then subjected to aq. workup (100 ml hexane and 100 ml H_2O), the aq. phase was extracted with hexane (20 ml), and the combined org. phases were washed successively with H_2O (50 ml) and brine (30 ml) and dried (Na_2SO_4). Filtration, removal of volatile components *in vacuo* followed by CC of the residue (gradient elution: hexane → hexane/Et_2O 20:1) furnished product **1d** (3.43 g, 97% yield) as a clear, colorless oil. IR (film): 3090–2880 (H–C=, H–C–), 1755 (C=O), 1495–1460 (C=C), 1395 (SO_2), 1240 (C–F), 1215 (C–F), 1140 (SO_2). ^{1}H-NMR (270 MHz, C_6D_6): 0.75 (*t*, Me); 3.47 (br. *d*, $^2J=18.3$, $CH_AH_BCO_2Et$); 3.71 (m_c, $MeCH_2O$); 3.89 (br. *d*, $^2J=18.2$, $CH_AH_BCO_2Et$); 4.34 (br. *d*, $^2J=14.6$, CH_AH_BPh); 4.80 (br. *d*, $^2J=14.6$, CH_AH_BPh); 6.96–7.05 (*m*, 5 arom. H). ^{13}C-NMR (67.5 MHz, $CDCl_3$): 13.9 (*q*, Me); 47.1 (*t*, CH_2CO_2Et); 53.0 (*t*, CH_2Ph); 61.8 (*t*, $MeCH_2O$); 128.9 (*d*, C_p); 129.0, 129.1 (2*d*, C_o, C_m); 133.1 (*s*, C_{ipso}); 167.3 (*s*, C=O). MS (EI, 80 eV): 474 (<1, $[M-H]^+$), 430 (<1, $[M-OEt]^+$), 403 (1, $[M-C_3H_4O_2]^+$), 402 (4, $[M-CO_2Et]^+$), 388 (3, $[M-CH_2CO_2Et]^+$), 228 (2, $[M-CF_3(CF_2)_3-C_2H_4]^+$), 219 (1, $[CF_3(CF_2)_3]^+$), 192 (89, $[M-CF_3(CF_2)_3SO_2]^+$), 164 (3, $[M-CF_3(CF_2)_3SO_2-C_2H_4]^+$), 131 (2, $[CF_2{=}CFCF_2]^+$), 119 (6, $[CH_2{=}NCH_2Ph]^+$ or $C_2F_5^+$), 118 (35, $[CH_2{=}N{=}CHPh]^+$), 107 (1, $C_7H_9N^+$), 106 (2, $C_7H_8N^+$), 105 (2, $C_7H_7N^+$), 104 (2, PhC≡NH^+), 100 (2, $C_2F_4^+$), 92 (22, $PhMe^+$), 91 (100, $PhCH_2^+$), 77 (2, $C_6H_5^+$), 69 (11, CF_3^+), 65 (14, HSO_2^+), 64 (2, $[H_2NSO]^+$ or SO_2^+), 63 (2, $HNSO^+$), 62 (1, NSO^+), 61 (2, $C_2H_5O_2^+$), 60 (3, $C_2H_4O_2^+$), 59 (2, $C_2H_3O_2^+$), 51 (3, HCF_2^+), 50 (1, CF_2^+), 39 (4, HC_2N^+ or F_2^+), 31 (2, CH_3O^+), 29 (16, $C_2H_5^+$), 28 (4, $C_2H_4^+$ or HC≡NH^+), 27 (5, $C_2H_3^+$ or HCN^+). Anal. calc. for $C_{15}H_{14}F_9NO_4S$ (475.3): C 37.90, H 2.97, N 2.95; found C 37.83, H 2.76, N 2.97.

X-Ray Crystal-Structure Determination of **1c** (see *Fig. 3*). A colorless needle of size 0.18 × 0.22 × 0.75 mm was grown from $CHCl_3$ and measured on a *Bruker Smart 1000 CCD* diffractometer with MoK_α ($\lambda=0.71073$ Å). The structure was solved by direct methods by means of SHELXS86 [32]. Non-H-atoms were refined anisotropically with SHELXL97 [33]; H-atoms were calculated at idealized positions and refined with isotropic displacement parameters: $C_{18}H_{14}F_9NO_2S$, M_r 479.37, $a=6.1579(7)$ Å, $b=20.729(2)$ Å, $c=30.716(4)$ Å, $\beta=94.471(2)°$, monoclinic, $P2_1/n$, $Z=8$, $\mu=0.265$ mm^{-1}, $F(000)=1936$, $\rho_{calc.}=1.629$ g·cm^{-3}, $T=133(2)$ K, ω scans, scan width 0.3°, $2.6°<2\theta<58.0°$. The measurement was monitored with SMART [34], integration performed with SAINT [34] and absorption corrected empirically with SADABS [34] ($T_{min}=0.78$, $T_{max}=1.00$), 34895 measured reflections, 9552 unique, 7483 observed reflections with $|F_o|>4\sigma(F_o)$, 581 parameters, final $R=4.40\%$, $wR_2=15.54\%$, goodness-of-fit 1.041, $\Delta\rho$ (max, min) in final *Fourier* synthesis 0.88 e Å^{-3}, −0.48 e Å^{-3} pointing to a small portion of disorder in the perfluorobutyl chain of one of two independent molecules that could not be resolved. Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the *Cambridge Crystallographic Data Centre* as deposition No. CCDC-187041. Copies of the data can be obtained, free of charge, on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ UK (fax: +44 (1223) 336 033; email: deposit@ccdc.cam.ac.uk).

REFERENCES

[1] M. Oki, *Top. Stereochem*. **1983**, *14*, 1.
[2] H. Kessler, *Angew. Chem*. **1970**, *82*, 237; *Angew. Chem., Int. Ed.* **1970**, *9*, 219; W. E. Stewart, T. H. Siddall III, *Chem. Rev.* **1970**, *70*, 517.
[3] L. Lunazzi, G. Cerioni, E. Foresti, D. Macciantelli, *J. Chem. Soc., Perkin Trans. 2* **1978**, 686; M. N. Ramos, S. R. Pereira, *J. Chem. Soc., Perkin Trans. 2* **1986**, 131.
[4] S. Sternhell, 'Rotation about Single Bond in Organic Molecules', in 'Dynamic Nuclear Magnetic Resonance Spectroscopy', Ed. L. M. Jackman, F. A. Cotton, Academic Press, New York, 1975, p. 163–201.
[5] W. B. Jennings, R. Stratt, *J. Chem. Soc., Chem. Commun*. **1970**, 1418.
[6] S. Lehmann, G. W. Buchanan, C. Bensimon, J. Hartmann, W. Schroth, *J. Chem. Soc., Perkin Trans. 2* **1996**, 467.
[7] E. Kleinpeter, M. Kretschmer, R. Borsdorf, R. Widera, M. Mühlstädt, *J. Prakt. Chem*. **1980**, *322*, 793.
[8] C. Yamagami, N. Takao, Y. Takeuchi, *Aust. J. Chem*. **1986**, *39*, 457.
[9] M. Webel, H.-U. Reissig, *Synlett* **1997**, 1141; I. M. Lyapkalo, M. Webel, H.-U. Reissig, *Synlett* **2001**, 1293. I. M. Lyapkalo, M. Webel, H.-U. Reissig, *Eur. J. Org. Chem.* **2001**, 4189; I. M. Lyapkalo, M. Webel, H.-U. Reissig, *Eur. J. Org. Chem.* **2002**, 1015; I. M. Lyapkalo, M. Webel, H.-U. Reissig, *Eur. J. Org. Chem.* **2002**, 3646.
[10] F. A. L. Anet, R. D. Trepka, D. J. Cram, *J. Am. Chem. Soc.* **1967**, *89*, 357.
[11] A. G. M. Barrett, D. C. Braddock, P. W. N. Christian, D. Pilipauskas, A. J. P. White, D. J. Williams, *J. Org. Chem*. **1998**, *63*, 5818.
[12] A. Liden, C. Roussel, T. Liljefors, M. Chanon, R. E. Carter, J. Metzger, J. Sandström, *J. Am. Chem. Soc*. **1976**, *98*, 2853; I. Pettersson, U. Berg, *J. Chem. Soc., Perkin Trans. 2* **1985**, 1365.
[13] G. Binsch, *Top. Stereochem*. **1968**, *3*, 97; R. F. Hobson, L. W. Reeves, K. N. Shaw, *J. Phys. Chem*. **1973**, *77*, 1228.
[14] K. B. Wiberg, P. R. Rablen, D. J. Rush, T. A. Keith, *J. Am. Chem. Soc*. **1995**, *117*, 4261.
[15] H. G. Richey, J. Farkas, *J. Org. Chem*. **1987**, *52*, 479; P. Sun, S. M. Weinreb, M. Shang, *J. Org. Chem*. **1997**, *62*, 8604.
[16] W. E. Truce, B. VanGemert, *J. Am. Chem. Soc*. **1978**, *100*, 5525.
[17] S. Cerezo, J. Cortes, M. Moreno-Manas, R. Pleixats, A. Roglans, *Tetrahedron* **1998**, *54*, 14869; B. J. McNelis, J. T. Starr, H. Dang, *J. Heterocycl. Chem*. **1998**, *35*, 1509.
[18] S. Tsushima, Y. Yamada, T. Onami, K. Oshima, M. O. Chaney, N. D. Jones, J. K. Swartzendruber, *Bull. Chem. Soc. Jpn*. **1989**, *62*, 1167.
[19] C. Suarez, C. B. LeMaster, C. L. LeMaster, M. Tafazzoli, N. S. True, *J. Phys. Chem*. **1990**, *94*, 6679.
[20] M. Spaeth, P. Plischka, F.-M. Bohnen, R. Herbst-Irmer, H. Laatsch, *J. Prakt. Chem*. **1997**, *339*, 243.
[21] R. S. Glass, R. J. Swedo, *Synthesis* **1977**, 798; D. J. Brown, J. A. Hoskins, *J. Chem. Soc., Perkin Trans. 1* **1972**, 522; W. E. Truce, L. W. Christensen, *Tetrahedron* **1969**, *25*, 181.
[22] J. B. Hendrickson, R. Bergeron, D. D. Sternbach, *Tetrahedron* **1975**, *31*, 2517; R. S. Glass, R. J. Swedo, *J. Org. Chem*. **1978**, *43*, 2291; S. Iyer, L. S. Liebeskind, *J. Am. Chem. Soc*. **1987**, *109*, 2759; C.-Y. Guo, R. L. Kirchmeier, J. M. Shreeve, *J. Fluorine Chem*. **1991**, *52*, 29; R. Ostwald, P.-Y. Chavant, H. Stadtmüller, P. Knochel, *J. Org. Chem*. **1994**, *59*, 4143; M. L. Edwards, D. M. Stemerick, J. R. McCarthy, *Tetrahedron* **1994**, *50*, 5579.
[23] C. D. Beard, K. Baum, *J. Am. Chem. Soc*. **1974**, *96*, 3237.
[24] D. Seebach, J. Gabriel, R. Hässig, *Helv. Chim. Acta* **1984**, *67*, 1083, and refs. cit. therein.
[25] W. R. Jackson, T. G. Kee, *J. Chem. Soc., Chem. Commun*. **1972**, 1154.
[26] P. J. Stang, M. Hanack, L. R. Subramanian, *Synthesis* **1982**, 85.
[27] A. Li, X. Bin, S.-Z. Zhu, *J. Fluorine Chem*. **1994**, *69*, 257; S. Benefice-Malouet, H. Blancou, R. Teissedre, A. Commeyras, *J. Fluorine Chem*. **1986**, *31*, 319.
[28] L. Xue, D. D. DesMarteau, W. T. Pennington, *Angew. Chem*. **1997**, *109*, 1389; *Angew. Chem., Int. Ed.* **1997**, *36*, 1331.
[29] G. Boche, *Angew. Chem*. **1989**, *101*, 286; *Angew. Chem., Int. Ed.* **1989**, *28*, 277.
[30] P. Satori, N. Ignat'ev, S. Datsenko, *J. Fluorine Chem*. **1995**, *75*, 157.
[31] B. H. Lipshutz, 'Organocopper Chemistry', in 'Organometallics in Synthesis. A Manual', Ed. M. Schlosser, John Wiley & Sons, Chichester, 2002, p. 671.
[32] G. M. Sheldrick, SHELXS86, Program for Crystal Structure Solution, University of Göttingen, Germany, 1986.
[33] G. M. Sheldrick, SHELXS97. Program for Crystal Structure Solution. University of Göttingen, Germany, 1997.
[34] SMART, SAINT, and SADABS, *Bruker AXS Inc.*, Madison, Wisconsin, USA, 1998.