Pergamon

Tetrahedron 57 (2001) 4337–4341

TETRAHEDRON

The reaction of per(poly)fluoroalkanesulfonyl azides with tertiary and secondary amines: generation and trapping of enamines

Yong Xu and Shizheng Zhu*

Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, 354 Fenglin Lu, Shanghai 200032, China

Received 19 January 2001; revised 6 March 2001; accepted 22 March 2001

Abstract—Per(poly)fluoroalkanesulfonyl azides decomposed readily at 0°C or ambient temperature in the presence of tertiary or secondary amines via a single electron transfer process and gave the corresponding fluoroalkanesulfonyl amides and *N*-fluoroalkanesulfonyl amidines. The formation of amidines was reasonably explained in terms of trapping of *N*-substituted vinylamine generated in situ with the azides.

1. Introduction

Nitrene generated thermally or photochemically from arenesulfonyl azides and alkoxylcarbonyl azides adds to the nitrogen atom of heteroaromatic bases to give the corresponding *N*-substituted imines.[1] For the arenesulfonyl azides, the decomposition to nitrene appears to require a fairly high temperature, usually between 120°C and 150°C.[2] The mechanisms for the decomposition of sulfonyl azides have been well established.[3] Particularly, they account for products obtained with xylene, pyridines and with *N*,*N*-dimethylaniline.[4] In the latter case, the product is considered to be *N*-(*p*-acetamidobenzenesulfonylimido)-dimethylaniline [Eq. (1)]:

$$RC_6H_4SO_2N_3 + PhNMe_2 \xrightarrow[130\text{-}140^oC]{reflux} RC_6H_4SO_2\text{-}N^-\text{-}N^+Me_2Ph \quad (1)$$

Recently we have investigated the reaction of per(poly)-fluoroalkanesulfonyl azides with pyridines and it was found that the reaction occurred around 110°C and provided *N*-fluoroalkanesulfonyl pyridinium imides and fluoroalkanesulfonyl amides.[5] As a continuation study on per-(poly)fluoroalkanesulfonyl azides,[5] which are one electron-poor azides, we found that they decomposed readily at room temperature or 0°C in the presence of tertiary and secondary amines, such as triethylamine and pyrrolidine, and yielded the corresponding perfluoroalkanesulfonyl amides, amidines. Herein we report these results.

2. Results and discussion

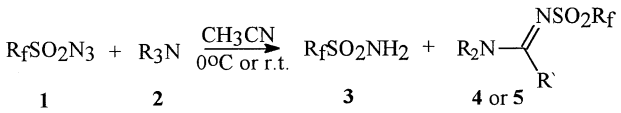
A solution of the perfluoroalkanesulfonyl azide **1a** in dry acetonitrile was treated with freshly distillated triethylamine at 0°C and nitrogen gas evolved. General work-up and purification gave two products. One was readily identified as the fluoroalkanesulfonyl amide **3a**. The second product obtained in 17% yield was a light yellow oil, which exhibited a set of signals characteristic of the structure of NEt_2 in its ^{1}H-NMR spectrum, was determined as *N′*-perfluorobutanesulfonyl-*N*,*N*-diethyl-formamidine **4** by comparison with the available sample in our laboratory.[6] Similarly, the reaction of fluoroalkanesulfonyl azide **1a** with tributylamine **2b** provided two products, fluoroalkanesulfonyl amide **3a** and

Table 1. The reaction results of azides **1** with tertiary amines **2**

Entry	Azides	Amines	Reaction temp. (°C)	Time (min)	Product (%)	
					3	**4** or **5**
1	**1a**	**2a**	0	30	69	17
2	**1b**	**2a**	0	30	46	9
3	**1a**	**2b**	25	60	76	13
4	**1b**	**2b**	25	60	53	13

Keywords: fluoroalkanesulfonyl azides; amidines; enamines; single electron transfer.
* Corresponding author. Tel.: +86(21)64163300-3525; fax: +86(21)64166128; e-mail: zhusz@pub.sioc.ac.cn

0040–4020/01/$ - see front matter
PII: S0040-4020(01)00376-3

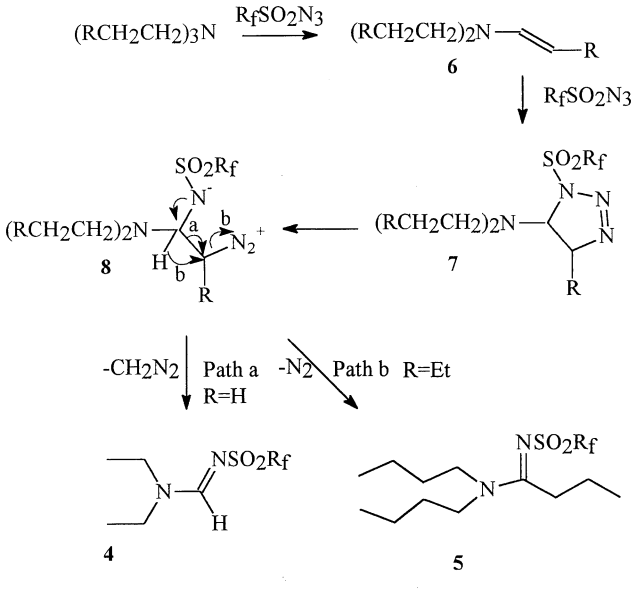


Scheme 1. R_f=C_4F_9, (a); $IC_2F_4OC_2F_4$, (b). R=Et (**2a**); Bu (**2b**). R=H (**4**); C_3H_7 (**5**).

N′-perfluorobutanesulfonyl-*N*,*N*-dibuthyl-butonamidine **5a** (see Table 1 and Scheme 1).

The formation of the amidines **4** and **5** are reasonably interpreted in terms of trapping of *N*,*N*-diethylvinylamine or dibutylvinylamine generated in the course of the reaction of amines with fluoroalkanesulfonyl azides. Recently, Murata et al. have reported the photolysis of *p*-nitrophenyl azide in the presence of triethylamine, which also yielded the unstable intermediate *N*,*N*-diethylvinylamine.[7] It is well known that sulfonyl azides react readily with electron-rich alkenes, such as enamines,[8] enamides,[9] and enol ethers,[10] to give [3+2] cycloaddition products. Recently, we have studied the reaction of fluoroalkanesulfonyl azides with enamines, which provided a triazoline intermediate.[11] In this case, the in situ-generated enamine reacted with fluoroalkanesulfonyl azides immediately and formed the unstable triazoline intermediate. The decomposition of the triazoline intermediate may occur by two possible mechanisms, as illustrated in Scheme 2. In the case of triethylamine, fragmentation to diazoalkane CH_2N_2 and *N*-sulfonyl amidines could be predominant (Path a).[12] Furthermore, the evolution of diazomethane from the reaction of vinylamine with benzenesulfonyl azide has been well established.[13] Alternatively, in the case of tributylamine the formed triazoline adduct may fragment by loss of nitrogen with concomitant or subsequent C_1 hydrogen migration to afford amidine **5** (Path b).

Moreover, to the best of our knowledge, the formation of amidines **4** and **5** are the first examples of trapping of *N*,*N*-diethylvinylamine or dibutylvinylamine at ambient temperature without photolysis. The *N*,*N*-diethylvinylamine, which is estimated to be a type of extremely unstable enamine,[14] is known to be produced in the photoreaction of an electron-accepting sensitizer with triethylamine.[15] Further, it has been established by CIDNP studies that the enamine is formed from the α-aminoethyl radical, $Et_2NCH{\cdot}CH_3$, produced through the proton transfer from the triethylamine radical cation to the sensitizer radical anion.[15a,c] It is reasonable to assume that in the reaction of fluoroalkanesulfonyl azides **1** with tertiary amine, the enamine is generated by the analogous mechanism involving a sequential electron and proton transfer. Thus, the isolation of the amidine, which implies the generation of the enamine, provides a direct indication that a single electron transfer participates in this reaction.

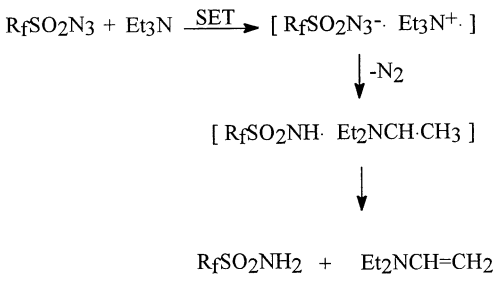


Scheme 2.

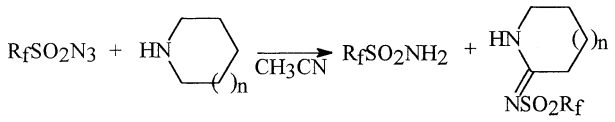
It is probable that the enamine is produced through a hydrogen transfer from the α-aminoethyl radical to the fluoroalkanesulfonylaminyl radical within the solvent cage. This expectation is supported by the observation that the use of a polar solvent, where the initially formed radical ion pair tends to dissociate into free radical ions is unfavorable for the formation of **6**, i.e. of the amidine. For example, when the reaction of azide **1b** with triethylamine was carried out in the more polar solvent pyridine, the yield of amidine dropped to 8% whereas the yield of amide increased to 77%.

The tentatively proposed reaction sequence is shown in Scheme 3. As per(poly)fluorinealkanesulfonyl azides are electron-poor azides, the electron transfer from tertiary amine to the azides gives a radical ion pair of $TEA^{+\cdot}$ and the azide radical anion, i.e. $[R_3N^{+\cdot}\ R_fSO_2N_3^{-\cdot}]$. Loss of N_2 from the azide radical anion $R_fSO_2N_3^{-\cdot}$ followed by the proton transfer from $TEA^{+\cdot}$, leads to the formation of amide **3** accompanied by the generation of enamine **6**. The amide radical anion has been postulated previously as a transient intermediate in the electron-chemical reduction of arenesulfonyl azides.[16]

The reaction of arenesulfonyl azides with secondary amines



Scheme 3.

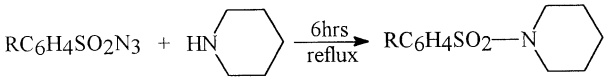


Scheme 4. R_f=C_4F_9, (a); $IC_2F_4OC_2F_4$, (b). n=0, (a); 1, (b).

Table 2. The reaction result of azides **1** with secondary amines **9**

Entry	Azides	Amines	Temp.(°C)	Time (h)	Product **10** yield (%)	Product **3** yield (%)
1	**2a**	**9a**	0	2	**10aa**: 8	60
2	**2b**	**9a**	0	2	**10ba**: 4	41
3	**2a**	**9b**	25	8	**10ab**: 41	47
4	**2b**	**9b**	25	12	**10bb**:17	36

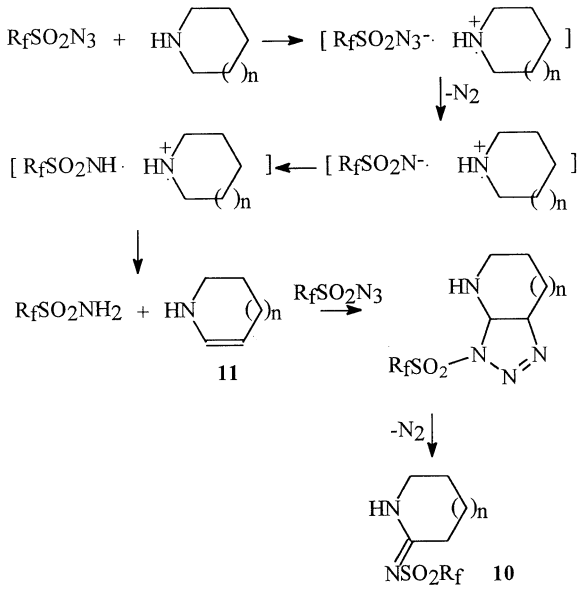
can occur under high temperature, usually refluxing with secondary amines, and provides the corresponding arene-sulfonyl amide, for example as in Eq. (2):[4]



(2)

As tertiary amines, we found that fluoroalkanesulfonyl azides reacted smoothly with cyclic secondary amines, such as piperidine and pyrrolidine, at 0°C or room temperature in acetonitrile, and nitrogen gas was liberated spontaneously. The products were easily identified as amidines **10** and amides **3** (Scheme 4 and Table 2).

The reaction may proceed in the same way as tertiary amines, i.e. electron transfer from the secondary amines to azides, then loss of nitrogen, proton transfer and formation of the cyclic enamine intermediate **11** (Scheme 5). The reactive cyclic enamine added to azide **1** in a 1,3-dipolar cycloaddition, which was followed by loss of nitrogen with concomitant rearrangement of hydride, afforded product **10**.[17] As the intermediate **11b** was more stable than **11a**, the yield of product **10b** was higher compared to **10a**.



Scheme 5.

3. Conclusions

In conclusion, we report the first example of azides reacting with tertiary and secondary amines through a single electron transfer process at 0°C or ambient temperature without photolysis. The reaction product *N*-fluoroalkanesulfonyl amidine was formed by trapping of *N*-substituted vinylamine which was generated through single electron transfer, loss of nitrogen and hydrogen transfer processes following the fragmentation of a triazoline adduct. Further work to elucidate the reactivity of these azides with amines is ongoing in our laboratory.

4. Experimental

Melting points were measured on a Temp-Melt apparatus. ^{1}H-NMR and ^{19}F-NMR spectra were recorded on a Varian-360L or Bruker AM-300 instrument with Me_4Si and $CFCl_3$ (with upfield negative) as internal and external standards, respectively. NMR spectra were recorded in chloroform-d unless otherwise stated. IR spectra were obtained with a Perkin–Elmer 983G spectrophotometer using KBr disks of the compounds. Low and high resolution mass spectra were obtained on HP 5989a and Finnigan MAT instruments, respectively. Elemental analyses were performed by this institute. All reactions as well as column chromatography were monitored routinely with the aid of TLC or ^{19}F-NMR spectroscopy. Acetonitrile was distilled from CaH_2 and reagents were purified before use.

4.1. General method for the reaction of Azide 1 with triethylamine

To a solution of perfluorobutanesulfonyl azides **1a** (0.425 g, 1.308 mmol) and acetonitrile 5 mL, was added triethylamine (0.264 g, 2.615 mmol) dropwise with stirring under a nitrogen atmosphere at 0°C. The resulting mixture was

stirred at 0°C until the starting reagents had disappeared (about 30 min, monitored by TLC). After removal of the excess solvent, the residue was chromatographed on a silica gel column. Elution with light petroleum ether (b.p. 60–90°C)– ethyl acetate (5:1) gave fluoroalkanesulfonyl amide **3a** (0.269 g, 0.900 mmol, 69%), and elution with light petroleum ether (b.p. 60–90°C)– ethyl acetate (2:1) gave **4a** (0.083 g, 0.217 mmol, 17%).

4.1.1. *N′*-Perfluorobutanesulfonyl-*N*,*N*-diethyl-formamidine (4a). Yellowish oil. Structural data agree with those of the literature.[6]

4.1.2. *N′*-1,1,2,2-Tetrafluoro-2-(1,1,2,2-tetrafluoro-2-iodoethoxy)-ethanesulfonyl-*N*,*N*-diethyl-formamidine (4b). Yellowish oil. Structural data agree with those of the literature.[6]

4.1.3. *N′*-Perfluorobutanesulfonyl-*N*,*N*-dibuthyl-butonamidine (5a). Colorless oil. ν_{max} (KBr)/cm^{-1} 2963m, 1558vs, 1474m, 1315m, 1239–1140vs. $\delta_H(CDCl_3)$: 3.44 (2H, t, J=7.9 Hz), 3.34 (2H, t, J=7.8 Hz), 2.79 (2H, t, J=8.1 Hz), 1.78 (2H, m), 1.62 (4H, m), 1.31 (4H, m), 1.06 (3H, t, J=7.4 Hz), 0.99 (3H, t, J=7.2 Hz), 0.92 (3H, t, J=7.4 Hz). $\delta_F(CDCl_3)$: −79.1 (CF_3, s), −112.0 (CF_2, m), −120.1 (CF_2, m), −124.7 (CF_2, m). *m/z* 481 (M^++1, 29.12), 437 (M^+—C_3H_7, 20.08), 261 (M^+—R_f, 100.00), 197 (M^+—SO_2R_f, 12.57), 128 ($C_8H_{18}N^+$, 100.00), 57 ($C_4H_9^+$, 7.50). HRMS, Calcd. 480.1493; Found. 480.1466.

4.1.4. *N′*-1,1,2,2-Tetrafluoro-2-(1,1,2,2-tetrafluoro-2-iodoethoxy)-ethanesulfonyl-*N*,*N*-dibuthyl-butonamidine (5b). Colorless oil. ν_{max} (KBr)/cm^{-1} 2962, 2875m, 1557vs, 1473m, 1330m, 1220–1080vs. $\delta_H(CDCl_3)$: 3.44 (2H, t, J=7.9 Hz), 3.34 (2H, t, J=7.8 Hz), 2.79 (2H, t, J=8.1 Hz), 1.78 (2H, m), 1.62 (4H, m), 1.31 (4H, m), 1.06 (3H, t, J=7.4 Hz), 0.99 (3H, t, J=7.2 Hz), 0.92 (3H, t, J=7.4 Hz). $\delta_F(CDCl_3)$: −63.6 (ICF_2, s), −79.7 (ICF_2CF_2, t, J=17 Hz), −84.6 (OCF_2, t, J=17 Hz), −116.3 (SO_2CF_2, s). *m/z* 605 (M^++1, 66.95), 561 (M^+—C_3H_7, 16.35), 261 (M^+—R_f, 11.94), 197 (M^+—SO_2R_f, 13.60), 128 ((C_4H_9)$_2N^+$, 100.00). HRMS for M^+—C_3H_7, Calcd. 560.99552; Found. 560.99316.

4.1.5. *N*-(2-Pyrrolidinylidene)-perfluorobutanesulfonyl-amide (10aa). White solid, m.p. 78–79°C. ν_{max} (KBr)/cm^{-1} 3220, 3162vs, 1620vs, 1460m, 1260–1100vs. $\delta_H(CDCl_3)$: 8.30 (1H, br), 3.72 (2H, t, J=7.2 Hz), 2.92 (2H, t, J=8.2 Hz), 2.22 (2H, m). $\delta_F(CDCl_3)$: −80.6 (CF_3, s), −113.5 (CF_2, m), −121.1 (CF_2, m), −125.6 (CF_2, m). *m/z* 366 (M^+, 12.18), 219 ($C_4F_9^+$, 4.35), 147 (M^+—C_4F_9, 100.00), 131 (M^+—OC_4F_9, 14.38), 69 (CF_3^+, 16.70). (Found: C, 26.32; H, 2.07; N, 7.81%. Calcd. for $C_8H_7F_9N_2O_2S$ C, 26.23; H, 1.93; N, 7.65%.)

4.1.6. *N*-(2-Pyrrolidinylidene)-1,1,2,2-tetrafluoro-2-(1,1,2,2-tetrafluoro-2-iodoethoxy)-ethanesulfonylamide (10ba). Reddish oil. ν_{max} (KBr)/cm^{-1} 3220, 3164vs, 2978m, 1619vs, 1449m, 1240–1120vs. $\delta_H(CDCl_3)$: 8.50 (1H, br), 3.70 (2H, t, J=7.4 Hz), 2.94 (2H, t, J=8.1 Hz), 2.24 (2H, m). $\delta_F(CDCl_3)$: −69.5 (ICF_2, s), −82.2 (ICF_2CF_2, t, J=17 Hz), −86.7 (OCF_2, t, J=17 Hz), −117.5 (SO_2CF_2, s). *m/z* 491 (M^++1, 100.00), 227 ($IC_2F_4^+$, 7.44), 147 (M^+—R_f, 87.35). HRMS for M^+, Calcd. 489.90522; Found. 489.90945.

4.1.7. *N*-(2-Piperidinylidene)-perfluorobutanesulfonyl-amide (10ab). White solid, m.p. 105–106°C. ν_{max} (KBr)/cm^{-1} 3251m, 2973m, 1622vs, 1489m, 1322, 1274–1139vs. $\delta_H(CDCl_3)$: 8.93 (1H, br), 3.44 (2H, s), 2.68 (2H, s), 1.81 (4H, s). $\delta_F(CDCl_3)$: −79.8 (CF_3, s), −107.0 (CF_2, m), −120.5 (CF_2, m), −125.2 (CF_2, m). *m/z* 381 (M^++1, 66.60), 219 ($C_4F_9^+$, 1.25), 161 (M^+—C_4F_9, 100.00), 82 ($C_5H_{10}N^+$, 16.63), 69 (CF_3^+, 17.08). (Found: C, 28.43; H, 2.37; N, 7.41%. Calcd. For $C_9H_9F_9NO_2S$ C, 28.42; H, 2.37; N, 7.37%.)

4.1.8. *N*-(2-Piperidinylidene)-1,1,2,2-tetrafluoro-2-(1,1,2,2-tetrafluoro-2-iodoethoxy)-ethanesulfonylamide (10bb). White solid, m.p. 49–50°C. ν_{max} (KBr)/cm^{-1} 3294m, 2965m, 1622vs, 1484m, 1322, 1220–1075vs. $\delta_H(CDCl_3)$: 8.93 (1H, br), 3.44 (2H, s), 2.68 (2H, s), 1.81 (4H, s). $\delta_F(CDCl_3)$: −63.4 (ICF_2, s), −80.3 (ICF_2CF_2, t, J=17 Hz), −84.1 (OCF_2, t, J=17 Hz), −125.3 (SO_2CF_2, s). *m/z* 505 (M^++1, 51.36), 446 (M^+—C_4H_{10}, 64.66), 227 ($IC_2F_4^+$, 5.77), 161 (M^+—R_f, 100.00), 55 ($C_4H_7^+$, 36.02). HRMS, Calcd. 503.92509; Found: 503.92119.

Acknowledgements

The authors wish to thank the National Natural Science Foundation of China (NNSFC, No. 200032010 and No. 200072049) and the Innovative Foundation of Chinese Academy of Sciences for financial support.

References

1. (a) *Azides and Nitrenes*, Scriven, E. V. F., Ed.; Academic Press: New York, 1984. (b) Tamura, Y.; Ikeda, M. *Adv. Heterocycle Chem.* **1981**, *29*, 73–130.
2. Bollinger, F. W.; Tuma, L. D. *Synlett.* **1996**, 407–413.
3. Heacock, J. F.; Edmison, M. T. *J. Am. Chem. Soc.* **1960**, *82*, 3460–3463.
4. Crenlyn, R. J. W. *J. Chem. Soc.* **1965**, 1132–1137.
5. (a) Xu, Y.; Xu, G. L.; Zhu, S. Z.; Zhu, G. Y.; Jia, Y. S.; Huang, Q. C. *J. Fluorine Chem.* **1999**, *96* (1), 79–86. (b) Xu, Y.; Zhu, S. Z. *Tetrahedron* **1999**, *55*, 13725–13734.
6. Xu, G. L.; Xu, B.; Qin, C. Y.; Zhu, S. Z. *J. Fluorine Chem.* **1997**, *84*, 25–28.
7. Murata, S.; Mori, Y.; Satoh, Y.; Yoshidome, R.; Tomioka, H. *Chem. Lett.* **1999**, 597–598.
8. (a) Fusco, R.; Bianchetti, G.; Pocar, D. *Gazz. Chim. Ital.* **1961**, *91*, 849–865. (b) Erba, E.; Mai, G.; Pocar, D. *J. Chem. Soc., Perkin Trans. I* **1992**, 2709–2712. (c) Battistini, M.; Era, E.; Pocar, D. *J. Chem. Soc., Perkin Trans. I* **1993**, 339–342.
9. Kadaba, P. K. *J. Org. Chem.* **1992**, *57*, 3075–3078.
10. Huisgen, R.; Sezimies, G. *Chem. Ber.* **1965**, *98*, 1153–1158.
11. (a) Xu, Y.; Wang, Y. L.; Zhu, S. Z. *Synthesis* **2000**, *4*, 513–516. (b) Xu, Y.; Wang, Y. L.; Zhu, S. Z. *J. Fluorine Chem.* **2000**, *104* (2), 195–200.
12. (a) Kucera, J.; Arnold, Z. *Tetrahedron Lett.* **1966**, 1109–1111. (b) Quast, H.; Ivanova, S. E. *J. Org. Chem.* **2000**, 1229–1233.
13. Fusco, R.; Bianchetti, G.; Pocar, D.; Ugo, R. *Chem. Ber.* **1963**, *96*, 802.

14. (a) Goez, M.; Rozwadowski, J.; Marciniak, B. *J. Am. Chem. Soc.* **1996**, *118*, 2882–2891. (b) Goez, M.; Zubarev, Z.; Echert, G. *J. Am. Chem. Soc.* **1998**, *120*, 5347–5348.
15. (a) Roth, H. D.; Manion, M. L. *J. Am. Chem. Soc.* **1975**, *97*, 6886–6888. (b) Ci, X.; Silva, R. S.; Nicodem, D.; Whitten, D. G. *J. Am. Chem. Soc.* **1989**, *111*, 1337–1343. (c) Goez, M.; Sartorius, I. *J. Am. Chem. Soc.* **1993**, *115*, 11123–11133.
16. Herbranson, D. E.; Hawley, M. D. *J. Org. Chem.* **1990**, *55*, 4297–4303.
17. Xu, Y.; Wang, Y. L.; Zhu, S. Z.; Zhu, G. Y.; Jia, Y. S.; Huang, Q. C. *J. Fluorine Chem.* **2000**, *106*, 133–138.