JOC The Journal of Organic Chemistry
Cite This: J. Org. Chem. XXXX, XXX, XXX−XXX
Article
pubs.acs.org/joc

Fe_2O_3-Promoted Intermolecular Chlorotrifluoromethylthiolation of Alkenes

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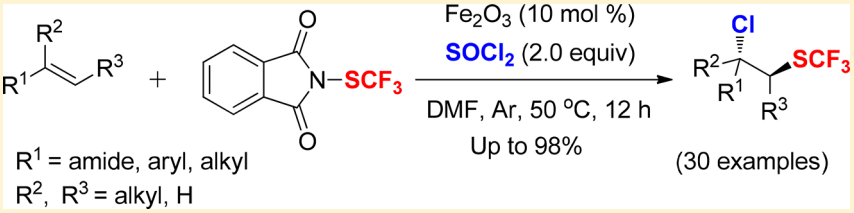
Supporting Information



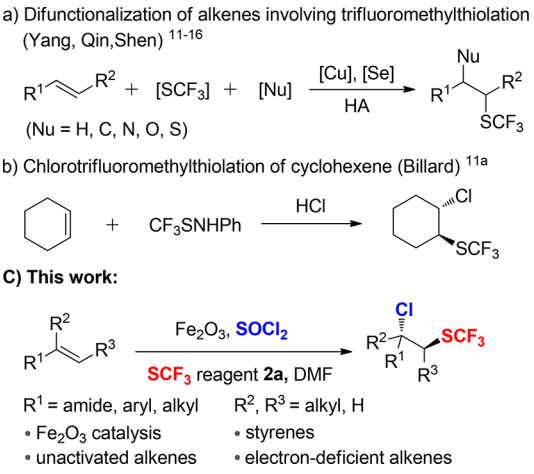
ABSTRACT: A simple, convenient method for intermolecular chlorotrifluoromethylthiolation of alkenes by using a low-cost and more abundant iron catalyst has been developed. This protocol provides a straightforward way to synthesize a variety of useful SCF_3-containing chlorides from a wide range of alkenes, including electron-deficient, aromatic, and unactivated alkenes. Mechanistic studies indicate that this is a free radical transformation, and the stronger electrophilic trifluoromethylthiolating reagent CF_3SCl was generated in situ under the employed conditions. The synthetic applications of this approach were also explored by a variety of synthetically useful transformations.

INTRODUCTION

Fluorinated organic compounds have many important applications in life sciences due to their potential improvement of physical, chemical, and biological properties.[1] In particular, the SCF_3 group, which possesses strong electron-withdrawing properties and a large Hansch lipophilicity parameter (π = 1.44), is considered as a useful structural motif in many pharmaceutical and agrochemical products, such as tiflorex and vaniliprole.[2] As a result, the development of new synthetic approaches for highly efficient and reliable introduction of a SCF_3 group into small molecules has become a hotspot of organic synthesis.[3] For instance, a number of transition metal- or organocatalyst-mediated methods for the trifluoromethylthiolation of (alkanes) arenes,[4] halides,[5] alcohols,[6,7] amines,[6a,7] alkynes,[4a,6a,8] and the corresponding boronic acids[4a,8d,9] have been successively reported.

In recent years, the trifluoromethylthiolation of alkenes has attracted much attention; many effective methods using electrophilic trifluoromethylthiolation reagents, such as Munavalli's,[10] Billard's,[11a] and Shen's[6a] SCF_3 reagents, have been intensively studied. Therefore, a variety of difunctionalizations of alkenes involving trifluoromethylthiolation, such as oxy-,[11,12b] amino-,[11c,12] hydro-,[13] thio-,[14] aryl-,[15] and halo-containing[11a,16] trifluoromethylthiolation, have also been described (Scheme 1a and 1b). However, there are only a few known methodologies for the development of a similar vicinal chlorotrifluoromethylthiolation of alkenes.[11a,16] Their applications suffer from some limitations, such as the use of toxic and difficult to handle gaseous CF_3SCl as the SCF_3 source, extremely low reaction temperatures, and a narrow range of alkenes. For example, a similar chlorotrifluoromethylthiolation of alkene with an electrophilic SCF_3 reagent by use of cyclohexene as the substrate has been successfully described, mediated by a stoichiometric Brønsted acid (Scheme 1b).[11a] Again, this was an isolated example, and the reaction was not explored further. Therefore, the development of a less expensive, milder, and more convenient procedure for the synthesis of SCF_3 chlorides which could be applied to a wide range of alkenes is still very attractive. Moreover, organochlorine molecules also serve as useful building blocks, which

Scheme 1. Previous and Present Works



Received: December 25, 2017

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DOI: 10.1021/acs.joc.7b03261
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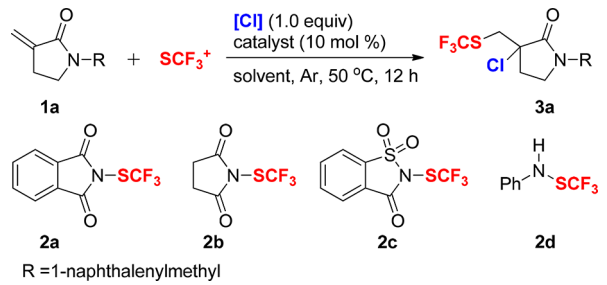
can be readily transformed into amines, hydroxyls, hydrocarbons, alkenes, and hydrogen. In continuation of our research interests on the difunctionalization of alkenes,[17] we herein present a powerful protocol for the intermolecular chlorotrifluoromethylthiolation of electron-deficient, unactivated alkenes and styrenes with $SOCl_2$ as the chlorine source under iron catalysis[18] (Scheme 1c).

RESULTS AND DISCUSSION

The investigation was initiated by using 3-methylene-1-(1-naphthylmethyl)-2-pyrrolidinone **1a** as the model substrate to optimize the reaction conditions (Table 1). First, the conditions described by Billard et al.[11a] were employed in the chlorotrifluoromethylthiolation of electron-deficient alkenes. To our surprise, no desired chlorotrifluoromethylthiolated adducts were observed (Scheme 2).

Table 1. Condition Optimization[a]

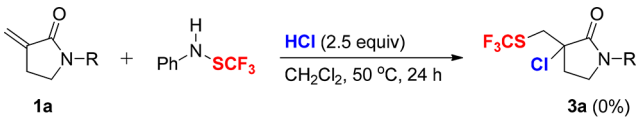


entry	SCF_3^+	catalyst	solvent	[Cl]	yield (%)[b]
1	**2a**	–	DMF	$SOCl_2$	20
2	**2a**	TfOH	DMF	$SOCl_2$	33
3	**2a**	$TsOH·H_2O$	DMF	$SOCl_2$	32
4	**2a**	$BF_3·Et_2O$	DMF	$SOCl_2$	30
5	**2a**	$FeCl_2$	DMF	$SOCl_2$	33
6	**2a**	$FeCl_3$	DMF	$SOCl_2$	2
7	**2a**	Fe_2O_3	DMF	$SOCl_2$	47
8	**2a**	Fe_3O_4	DMF	$SOCl_2$	18
9[c]	**2a**	Fe_2O_3	DMF	$SOCl_2$	85
10[d]	**2a**	Fe_2O_3	MFA	$SOCl_2$	45
11	**2a**	Fe_2O_3	$CHCl_3$	$SOCl_2$	NR
12	**2a**	Fe_2O_3	THF	$SOCl_2$	NR
13	**2a**	Fe_2O_3	toluene	$SOCl_2$	NR
14	**2a**	Fe_2O_3	CH_3CN	$SOCl_2$	NR
15	**2b**	Fe_2O_3	DMF	$SOCl_2$	42
16	**2c**	Fe_2O_3	DMF	$SOCl_2$	49
17	**2d**	Fe_2O_3	DMF	$SOCl_2$	48
18	**2a**	Fe_2O_3	DMF	$(COCl)_2$	77
19	**2a**	Fe_2O_3	DMF	TMSCl	NR
20	**2a**	Fe_2O_3	DMF	NCS	NR
21	**2a**	Fe_2O_3	DMF	Bu_4NCl	NR

[a]General conditions: **1a** (0.1 mmol), SCF_3^+ (0.15 mmol, 1.5 equiv), catalyst (10 mol %), and $SOCl_2$ (0.1 mmol, 1.0 equiv) in solvent (1.0 mL) at 50 °C for 12 h. [b]Refers to ^{19}F NMR yield using $PhCF_3$ as the internal standard. [c]Reaction performed with 2.0 equiv of **2a** and $SOCl_2$. [d]MFA = *N*-methylformanilide.

Then the reaction was carried out with Munavalli's SCF_3 reagent **2a** (1.5 equiv) and thionyl chloride (1.0 equiv) in the absence of catalyst in DMF at 50 °C under an argon atmosphere for 12 h. To our delight, the expected product 3-chloro-1-(1-naphthylmethyl)-3-trifluoromethylthiomethyl-2-pyrrolidinone **3a** was formed in a 20% yield (Table 1, entry 1).

Scheme 2. Chlorotrifluoromethylthiolation



To improve the yield further, a series of Brønsted acids and Lewis acids were employed as catalysts for the next investigation. When 10 mol % of TfOH or $TsOH·H_2O$ was used as the activator, the desired product **3a** was obtained in 33% and 32% yields, respectively (Table 1, entries 2 and 3). Similar yields of **3a** were also obtained when $BF_3·Et_2O$ and $FeCl_2$ were used as the catalyst (Table 1, entries 4 and 5). Inspired by these results, we applied different ferrous complexes, such as $FeCl_3$, Fe_2O_3, and Fe_3O_4, to the reaction separately (Table 1, entries 6–8). It showed that Fe_2O_3 performed well and increased the yield to 47% (Table 1, entry 7). Meanwhile, other metal catalysts, such as Al, Ni, Cu, Zn, Pd, and In complexes, were investigated, but no superior result was obtained (see Table S1 in Supporting Information). Interestingly, when the amounts of both **2a** and $SOCl_2$ were increased to 2.0 equiv, the yield of the product was increased significantly to 85% (Table 1, entry 9). Subsequently, optimization of the reaction was aimed at exploring the effectiveness of solvent. A lower yield was obtained when the solvent was changed to MFA (Table 1, entry 10). It should be noted that no reaction occurred in other solvents such as $CHCl_3$, THF, toluene, or CH_3CN (Table 1, entries 11–14), indicating that thionyl chloride undergoes formamide reagent DMF or MFA to generate a Vilsmeier reagent intermediate[19] which could produce a strong nucleophilic chloride anion to drive the difunctionalization of alkene. Afterward, other electrophilic SCF_3^+ reagents such as **2b**, **2c**, and **2d** were also evaluated but were much less efficient than **2a** (Table 1, entries 15–17). Finally, different chlorine sources were explored. Oxalyl chloride provided the desired product in 77% yield (Table 1, entry 18). When TMSCl, NCS, and Bu_4NCl were employed as chlorine sources, no reactions occurred (Table 1, entries 19–21).

After the above optimized reaction conditions (Table 1, entry 9) were obtained, a study on the scope and limitations of this transformation was carried out, and the results are summarized in Scheme 3. First, a series of five-membered α,β-unsaturated cyclic amides with different alkyl and aryl substituents on the nitrogen atom were compatible with the reaction conditions, affording the corresponding products in excellent yields (**3a–e**, Scheme 3). Encouraged by these promising results, we examined styrene under the same reaction conditions. To our satisfaction, the desired product **3f** was obtained in 72% yield. Then various styrenes bearing either electron-rich or electron-deficient substituents on the phenyl ring all underwent the chlorotrifluoromethylthiolation smoothly to provide the corresponding 2-chloro-2-phenylethyltrifluoromethylsulfanes **3g–o** in good yields. For example, when substituents such as methyl, acetoxyl, fluoro, or bromo were introduced to the para-position of the aromatic ring, the corresponding products **3l–o** were obtained in high yields (77–90%). Finally, fused ring styrenes such as 1- and 2-vinylnaphthalene were used as the substrates, leading to products **3p** and **3q** in 80% and 84% yields, respectively.

DOI: 10.1021/acs.joc.7b03261
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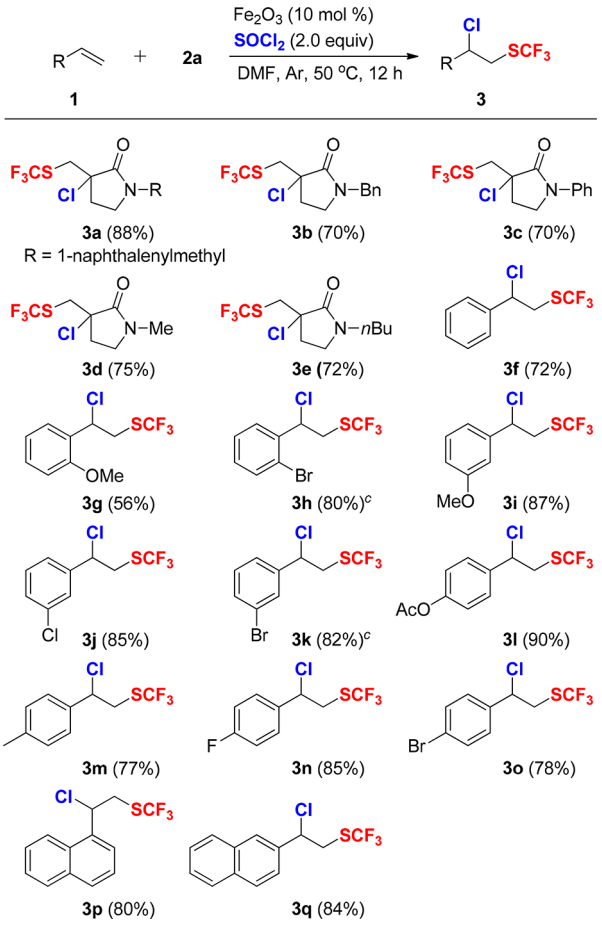
Scheme 3. Substrate Scope for Terminal Alkenes[a,b]



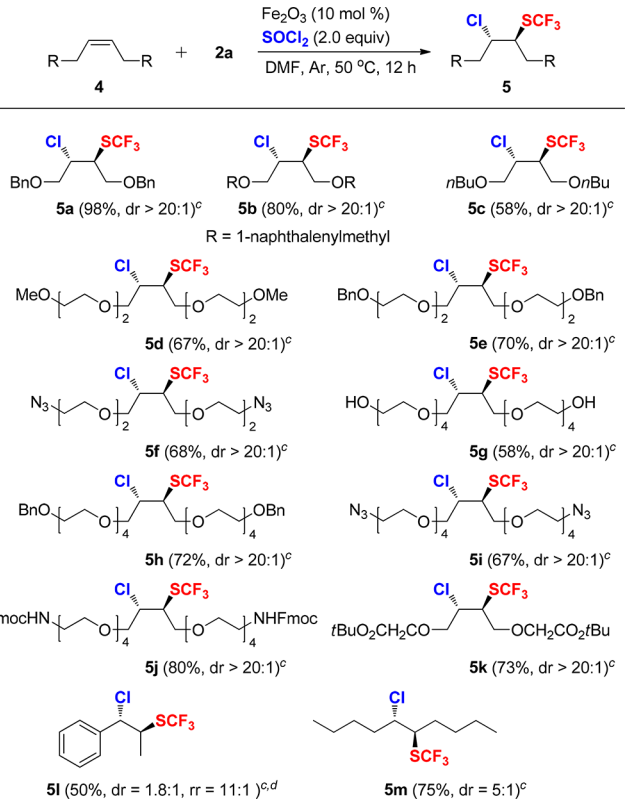
[a]General conditions: **1** (0.2 mmol), **2a** (0.4 mmol, 2.0 equiv), Fe_2O_3 (10 mol %), and $SOCl_2$ (0.4 mmol, 2.0 equiv) in DMF (2.0 mL) at 50 °C for 12 h. [b]Isolated yield. [c]Yield was determined by ^{19}F NMR spectroscopy using $PhCF_3$ as an internal standard.

Next, to further broaden the substrate scope, internal alkenes were also examined (Scheme 4). Gratifyingly, only one diastereomer **5a** was found in 98% yield when a cis configuration of 1,4-bis(benzyloxy)-2-butene **4a** was employed under the above reaction conditions. For comparison, the trans version of alkene was also tested but no reaction occurred, probably because its bulky benzyloxy groups sterically hindered the binding of SCF_3 to the alkene. As an example, when the less hindered *trans*-5-decene was tested, the corresponding product **5m** was obtained in 75% yield. Subsequently, *cis*-2-butenes bearing 1-naphthalenylmethyl, *n*Bu, or *tert*-butyl acetate on the oxygen atom were suitable substrates for the reaction and afforded **5b**,**c** and **5k** in good yields and with good diastereoselectivity. It is worth noting that when functional polyethylene glycols (PEGs) were linked to 2-butenes, the reactions proceeded smoothly to generate the corresponding products **5d**–**j**. When asymmetric internal alkene *cis*-1-phenylpropene was tested, the corresponding product **5l** was obtained in 50% yield and with excellent regioselectivity.

To evaluate the efficiency and practicability of this approach, the reaction scale was increased from 0.2 to 2.9 mmol. The desired product **3p** was obtained without a significant change in the yield (Scheme 5).

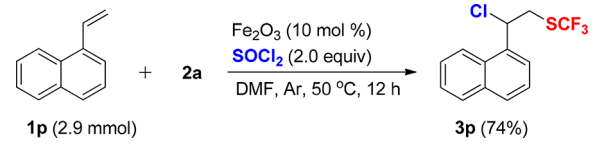
The C–Cl bond of **3p** is much more reactive than a regular secondary C–Cl bond, and it could be converted into various

Scheme 4. Substrate Scope for Internal Alkenes[a,b]



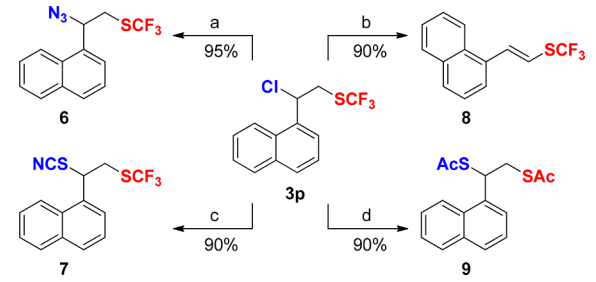
[a]General conditions: **4** (0.2 mmol), **2a** (0.4 mmol, 2.0 equiv), Fe_2O_3 (10 mol %), and $SOCl_2$ (0.4 mmol, 2.0 equiv) in DMF (2.0 mL) at 50 °C for 12 h. [b]Isolated yield. [c]The ratio of diastereomers was determined by ^1H NMR and ^{19}F NMR of the crude product. [d]rr = Regiomeric ratio.

Scheme 5. Scale-up of Fe_2O_3-Catalyzed Chlorotrifluoromethylthiolation



derivatives. As shown in Scheme 6, **3p** undergoes a nucleophilic attack by NaN_3 or KSCN to produce corresponding azide **6** and isothiocyanate **7** in 95% and 90% yields, respectively.

Scheme 6. Synthetic Transformations[a]



[a]Reaction conditions: (a) NaN_3 (1.5 equiv), DMF, 80 °C, 8 h. (b) piperidine, 50 °C, 8 h. (c) KSCN (1.5 equiv), DMF, 80 °C, 8 h. (d) KSAc (2.0 equiv), DMF, 80 °C, 8 h.

DOI: 10.1021/acs.joc.7b03261
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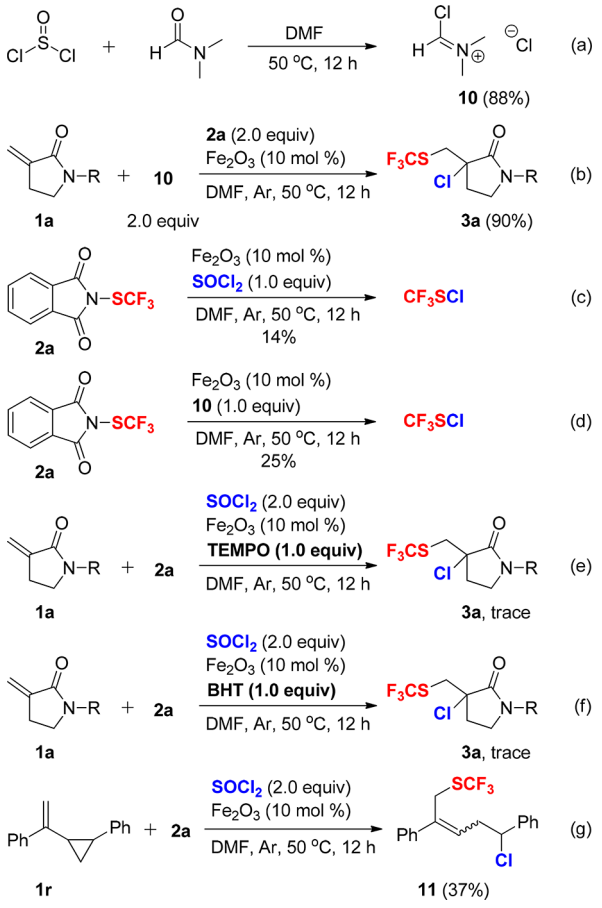
Treatment of **3p** with piperidine generated the elimination product **8** in high yield (90%) and selectivity (*E*-alkene). Interestingly, SCF_3 acted as a leaving group when strong nucleophile KSAc was employed, and the disulfide **9** was observed in 90% yield.

To gain insight into the reaction mechanism, several control experiments were conducted under the standard conditions (Scheme 7). When thionyl chloride was treated with DMF after

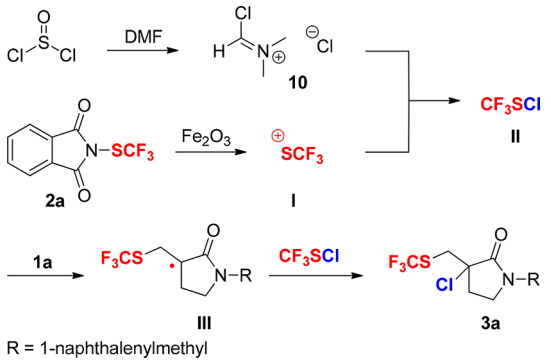
Scheme 7. Control Experiments



12 h, only Vilsmeier intermediate **10** was obtained in 88% yield. Then **10** was employed as the chlorine source instead of $SOCl_2$ and subjected to chlorotrifluoromethylthiolation under the optimal reaction conditions, and a high yield was observed. These experiments may indicate that the true chlorine source of the transformation was possibly from the Vilsmeier intermediate **10**. In addition, a 14% yield (determined by ^{19}F NMR) of CF_3SCl could be obtained when **2a** was treated in the absence of alkene (Scheme 7c). For comparison, employing Vilsmeier intermediate **10** as the chlorine source gave CF_3SCl in 25% yield (determined by ^{19}F NMR). It is worthy to note that the electrophilic trifluoromethylthiolating capability of CF_3SCl was stronger than Munavalli's reagent **2a**.[20] When 1.0 equiv of radical scavenger TEMPO (2,2,6,6-tetramethyl-1-piperidinyloxy) or BHT (2,6-di-*tert*-butyl-4-methylphenol) was respectively added to the reaction system of **1a**, the reaction was totally suppressed and no expected product **3a** was produced (Scheme 7e,f). Additionally, to further confirm that a SCF_3 radical was generated during the reaction, a radical-clock experiment was conducted. Compound **1r** afforded the ring-opened product **11** in 37% yield (Scheme 7g). These radical-trapping and radical-clock experiments may suggest that a radical process was possibly involved during the initial stage of this reaction.

Based on these preliminary results and previous related publications,[10−17,20] a plausible reaction pathway is proposed in Scheme 8. Initially, thionyl chloride reacts with DMF to afford

Scheme 8. Plausible Mechanism



activated Vilsmeier intermediate **10**. Simultaneously, an iron catalyst activates Munavalli's SCF_3 reagent **2a** to generate the SCF_3 cation **I**, which combines with Cl anion from Vilsmeier intermediate **10** to form intermediate CF_3SCl **II**. Then intermediate **II** reacts with alkene **1a**, resulting in radical intermediate **III**. Finally, radical intermediate **III** is trapped by the chlorine radical from CF_3SCl to generate the final chlorotrifluoromethylthiolated product **3a**.

CONCLUSION

We have established a simple and practical protocol for the difunctionalization of alkenes involving trifluoromethylthiolation using an inexpensive and stable iron catalyst. Both activated and unactivated alkenes were suitable for this reaction, and a wide range of functional groups were tolerated. Various trifluoromethylthiolated chlorides were obtained in good yields, which can be readily transformed to some valuable compounds. Further investigation into the mechanism and application is ongoing in our laboratory.

EXPERIMENTAL SECTION

General. ^1H, ^{19}F, and ^{13}C NMR spectra were recorded on a Bruker 400 or 500 MHz spectrophotometer. ^1H NMR spectra were referenced to tetramethylsilane (s, 0.00 ppm) using $CDCl_3$ as solvent, ^{13}C NMR spectra were referenced to solvent carbons (77.16 ppm for the middle peak, $CDCl_3$), and ^{19}F NMR spectra were referenced to 2% perfluorobenzene (s, −164.90 ppm) in $CDCl_3$. All reactions were performed under an argon atmosphere in a glovebox. LC-MS spectra were recorded on an Asilent LCMS-1100 spectrometer. GC-MS spectra were recorded on an Asilent 5975-MSD spectrometer.

Unsaturated amides **1a−e**,[17a] styrenes **1f−q**,[21] and trifluoromethylthiolation reagents **2a−d**[22,6a] were prepared according to reported procedures.

Synthesis of Substrates. Preparation of compounds **4a**, **4b**, **4c**, and **4k** (**4a** as an example).[23]

(Z)-1,4-Bis(benzyloxy)but-2-ene (4a). To a solution of (*Z*)-butene-1,4-diol (1.3 g, 14.9 mmol) in dry THF (50 mL) was added NaH (60% dispersion in mineral oil; 2.4 g, 59.6 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of benzyl bromide (7.6 g, 44.7 mmol) in dry THF (25 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess

DOI: 10.1021/acs.joc.7b03261
J. Org. Chem. XXXX, XXX, XXX−XXX

NaH was destroyed by careful addition of water (20 mL), and then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 40 mL), washed with saturated aqueous NH_4Cl solution (40 mL), water (40 mL), and brine (40 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 10:1) to generate the dibenzyl ether **4a** (3.2 g, 80%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.36−7.24 (m, 10H), 5.79 (t, J = 3.8 Hz, 2H), 4.49 (s, 4H), 4.06 (d, J = 4.7 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.2, 129.6, 128.5, 127.9, 127.8, 72.4, 65.9.

*(Z)-1,4-Bis(naphthalen-1-ylmethoxy)but-2-ene (**4b**).* The titled compound was obtained as clear oil in 72% yield, from (Z)-butene-1,4-diol and 1-(bromomethyl)naphthalene. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.09 (d, J = 7.6 Hz, 2H), 7.85 (d, J = 8.6 Hz, 2H), 7.80 (d, J = 8.0 Hz, 2H), 7.52−7.47 (m, 4H), 7.46−7.38 (m, 4H), 5.84 (t, J = 3.6 Hz, 2H), 4.90 (s, 4H), 4.11 (d, J = 3.8 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 133.9, 133.7, 131.9, 129. 8, 128.8, 128.7, 126.7, 126.3, 125.9, 125.3, 124.2, 70.9, 65.9. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{26}H_{24}O_2Na$: 391.1669; found: 391.1670.

*(Z)-1,4-Dibutoxybut-2-ene (**4c**).*[24] The titled compound was obtained as clear oil in 69% yield, from (Z)-butene-1,4-diol and 1-bromobutane. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 5.72 (t, J = 3.7 Hz, 2H), 4.04 (d, J = 4.7 Hz, 4H), 3.42 (t, J = 6.6 Hz, 4H), 1.60−1.53 (m, 4H), 1.40−1.35 (m, 4H), 0.92 (t, J = 7.4 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 129.6, 70.4, 66.6, 32.0, 19.5, 14.1.

*(Z)-Di-tert-butyl 2,2′-(But-2-ene-1,4-diylbis(oxy))-diacetate (**4k**).* The titled compound was obtained as clear oil in 82% yield from (Z)-butene-1,4-diol and *tert*-butyl 2-bromoacetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 5.78 (s, 2H), 4.18 (s, 4H), 3.96 (d, J = 4.7 Hz, 4H), 1.48 (s, 18H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.5, 129.3, 81.6, 67.8, 66.7, 28.1. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{16}H_{28}O_6Na$: 339.1778; found: 339.1782.

*(Z)-2,4,6,13,16,19-Hexaoxaicos-10-ene (**4d**).* To a solution of (Z)-butene-1,4-diol (4.0 g, 45.4 mmol) in Et_2O (50 mL) was added 4.6 mL of pyridine, the reaction mixture was stirred for 15 min, and then PBr_3 (27.0 g, 99.7 mmol) was slowly added by syringe. After addition, the resulting mixture was stirred at room temperature for 4 h. Water was added to quench the reaction. The organic layer was collected and dried with anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The residue was purified by flash chromatography on silica gel with petroleum ether to give (Z)-1,4-dibromobut-2-ene (7.6 g, 78%) as a yellow oil.

To a solution of 2-(2-methoxyethoxy)ethan-1-ol (0.6 g, 4.7 mmol) in dry THF (20 mL) was added NaH (60% dispersion in mineral oil; 0.2 g, 5.4 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of (Z)-1,4-dibromobut-2-ene (0.5 g, 2.3 mmol) in dry THF (10 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess NaH was destroyed by careful addition of water (20 mL), and then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 20 mL), washed with saturated aqueous NH_4Cl solution (40 mL), water (40 mL), and brine (40 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 5:1) to generate **4d** (0.88 g, 65%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 5.73 (t, J = 3.8 Hz, 2H), 4.10 (d, J = 4.6 Hz, 4H), 3.66−3.64 (m, 8H), 3.62−3.59 (m, 4H), 3.57−3.55 (m, 4H), 3.39 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 129.5, 72.0, 70.8, 70.7, 69.6, 67.0, 59.1. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{14}H_{28}O_6Na$: 315.1778; found: 315.1778.

*(Z)-1,20-Diphenyl-2,4,6,13,16,19-hexaoxaicos-10-ene (**4e**).* To a solution of 2,2-oxybis(ethan-1-ol) (8.6 g, 81.0 mmol) in dry THF (100 mL) was added NaH (60% dispersion in mineral oil; 1.2 g, 30.0 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of BnBr (3.5 g, 20.2 mmol) in dry THF (30 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess NaH was destroyed by careful addition of water (50 mL), and then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 40 mL), washed with saturated aqueous NH_4Cl solution (40 mL), water (40 mL), and brine (40 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 2:1) to generate the 2-(2-(benzyloxy)ethoxy)ethan-1-ol (1.8 g, 46%) as a colorless oil.

To a solution of 2-(2-(benzyloxy)ethoxy)ethan-1-ol (0.8 g, 4.1 mmol) in dry THF (30 mL) was added NaH (60% dispersion in mineral oil; 0.2 g, 4.9 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of (Z)-1,4-dibromobut-2-ene (0.4 g, 18.7 mmol) in dry THF (10 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess NaH was destroyed by careful addition of water (20 mL) then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 40 mL), washed with saturated aqueous NH_4Cl solution (20 mL), water (20 mL) and brine (20 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 3:1) to generate **4e** (0.5 g, 58%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.34 (d, J = 4.5 Hz, 8H), 7.32−7.27 (m, 2H), 5.72 (t, J = 3.8 Hz, 2H), 4.57 (s, 4H), 4.09 (t, J = 4.1 Hz, 4H), 3.69−3.62 (m, 12H), 3.61−3.58 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.3, 129.5, 128.5, 127.9, 127.7, 73.4, 70.8, 69.7, 69.5, 67.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{26}H_{36}O_6Na$: 467.2404; found: 467.2409.

*(Z)-1,16-Diazido-2,4,11,14-tetraoxahexadec-8-ene (**4f**).* A 100 mL round-bottom flask equipped with a magnetic stirrer and a reflux condenser was charged with an ethylene glycol derivative (10.0 g, 94.2 mmol). The solution was cooled to −10 °C. Then phosphorus tribromide (2.9 g, 10.8 mmol) was added dropwise, over 30 min, to the solution. Afterward, the temperature was increased slowly to room temperature and the reaction mixture was refluxed gently for 2 h. At the end of the reaction, the mixture was distilled under reduced pressure to give the monobromo ethylene glycol (3.0 g, 55%) as a colorless liquid.

The monobromo ethylene glycol (2.0 g, 11.8 mmol) was dissolved in H_2O (50 mL), and NaN_3 (2.0 g, 30.7 mmol) was added under stirring. Then the mixture was refluxed for 16 h. After cooling to room temperature, the mixture was poured into the sodium hydroxide solution and extracted with ethyl acetate. Evaporation of the organic phase gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 2:1) to generate 2-(2-azidoethoxy)ethan-1-ol (1.2 g, 78%) as a colorless oil.

To a solution of 2-(2-azidoethoxy)ethan-1-ol (1.1 g, 8.4 mmol) in dry THF (30 mL) was added NaH (60% dispersion in mineral oil; 0.3 g, 8.4 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of (Z)-1,4-dibromobut-2-ene (0.6 g, 2.8 mmol) in dry THF (10 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess NaH was destroyed by careful addition of water (20 mL), and then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 40 mL), washed with saturated aqueous NH_4Cl solution (20 mL), water (20 mL), and brine (20 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 4:1) to generate **4f** (0.7 g, 80%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 5.74 (t, J = 3.8 Hz, 2H), 4.12 (d, J = 4.7 Hz, 4H), 3.69−3.65 (m, 8H), 3.62−3.60 (m, 4H), 3.42−3.39 (t, J = 4.1 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 129.4, 72.4, 70.7, 70.0, 69.5, 66.9, 61.7, 50.7, 50.6. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{12}H_{22}N_6O_4Na$: 337.1595; found: 337.1598.

*(Z)-3,5,7,10,17,20,23,26-Octaoxaoctacos-14-ene-1,28-diol (**4g**).*[25] At 0 °C, under the atmosphere of Ar, to a suspension of NaH (1.6 g, 60% dispersed in mineral oil, 38.8 mmol, in 30 mL DMF) was added a solution of (Z)-butene-1,4-diol (1.1 g, 12.9 mmol) in DMF (10 mL). The mixture was stirred for 30 min at rt, and a solution of 1,3,6,9,12-pentaoxa-2-thiacyclotetradecane 2,2-dioxide (10.0 g, 39.0 mmol) in DMF (20 mL) was added at this temperature. The resulting mixture was stirred for 12 h at rt. DMF was removed under vacuum, the resulting residue was dissolved in THF. Then water (2.0 mL, 111.1 mmol) and H_2SO_4 were added to the reaction mixture to adjust the

DOI: 10.1021/acs.joc.7b03261
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pH to 3, and the resulting mixture was stirred for 6 h at rt. The reaction was quenched with saturated $NaHCO_3$ (100 mL). After removal of THF under vacuum, the solution was extracted with CH_2Cl_2 (100 × 4 mL). The organic layers were combined, dried over anhydrous Na_2SO_4, and concentrated under vacuum. The residue was purified by flash chromatography on silica gel ($MeOH/CH_2Cl_2$ = 20:1) to give **4g** (5.2 g, 90% yield) as a clear oil. ^1H NMR (400 MHz, $CDCl_3$) δ = 5.73 (t, J = 3.9 Hz, 2H), 4.10 (d, J = 4.5 Hz, 4H), 3.74−3.71 (m, 4H), 3.68−3.64 (m, 20H), 3.62−3.59 (m, 8H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 129.5, 72.8, 70.7, 70.6, 70.6, 70.3, 69.5, 66.9, 61.7.

*(Z)-1,32-Diphenyl-2,5,7,9,12,19,22,25,28,31-decaoxadotriacont-16-ene (**4h**).* To a solution of **4g** (0.7 g, 1.6 mmol) in dry THF (30 mL) was added NaH (60% dispersion in mineral oil; 0.2 g, 4.8 mmol) under argon. The reaction mixture was heated under reflux for 2 h and cooled to room temperature. A solution of BnBr (0.8 g, 4.8 mmol) in dry THF (10 mL) was added dropwise to the stirred mixture. The reaction mixture was then stirred and heated under reflux for 8 h. The excess NaH was destroyed by careful addition of water (20 mL), and then the THF was removed in vacuo. The residue was taken up in CH_2Cl_2 (3 × 40 mL), washed with saturated aqueous NH_4Cl solution (20 mL), water (20 mL), and brine (20 mL), and then dried ($MgSO_4$). Evaporation of the solvent gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 4:1) to generate **4h** (0.5 g, 51%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.33−7.27 (m, 10H), 5.71 (s, 2H), 4.55 (s, 4H), 4.07 (d, J = 3.2 Hz, 4H), 3.65−3.63 (m, 28H), 3.62−3.57 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.1, 129.2, 128.2, 127.5, 127.4, 73.0, 70.4, 70.4, 69.3, 69.2, 66.7. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{34}H_{52}O_{10}Na$: 643.3453; found: 643.3457.

*(Z)-1,28-Diazido-3,5,7,10,17,20,23,26-octaoxaoctacos-14-ene (**4i**).* **4g** (2.0 g, 4.5 mmol) was dissolved in 20 mL of THF, 8 N NaOH (2.3 mL) was added, and a solution of TsCl (2.2 g, 11.3 mmol) in dry THF (10 mL) was added dropwise to the stirred mixture at 0 °C. Stirring was maintained for 12 h at room temperature. The reaction mixture was poured on ice−water (20 mL) and extracted with ether (3 × 25 mL). Evaporation of the organic phase gave a residue which was purified by silica flash column chromatography (petroleum ether/EtOAc = 2:1) to generate (Z)-3,5,7,10,17,20,23,26-octaoxaoctacos-14-ene-1,28-diyl bis(4-methylbenzenesulfonate) (3.4 g, 42%) as a colorless solid.

(Z)-3,5,7,10,17,20,23,26-Octaoxaoctacos-14-ene-1,28-diyl bis(4-methylbenzenesulfonate) (0.8 g, 1.1 mmol) was dissolved in DMF (30 mL), and NaN_3 (0.2 g, 3.3 mmol) was added under stirring. Then the mixture was stirred at 80 °C for 12 h. After cooling to room temperature, DMF was removed under vacuum, and the resulting residue was purified by silica flash column chromatography (petroleum ether/EtOAc = 2:1) to generate **4i** (0.5 g, 95%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ = 5.72 (s, 2H), 4.10 (d, J = 3.9 Hz, 4H), 3.69−3.64 (m, 24H), 3.59 (dd, J = 5.8 Hz, 2.9 Hz, 4H), 3.40 (t, J = 4.8 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 129.5, 70.8, 70.8, 70.7, 70.7, 70.1, 69.6, 67.0, 50.8. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{20}H_{38}N_6O_8Na$: 513.2643; found: 513.2648.

*(Z)-Bis((9H-fluoren-9-yl)methyl) (3,5,7,10,17,20,23,26-Octaoxaoctacos-14-ene-1,28-diyl)-dicarbamate (**4j**).* **4i** (0.16 g, 0.3 mmol) and PPh_3 (0.20 g, 0.9 mmol) were dissolved in THF (20 mL), the mixture was stirred at room temperature for 2 h, and H_2O (100 μL) was added to the stirred mixture. Stirring was maintained for 12 h at room temperature. THF was removed under vacuum, and the resulting residue was dissolved in water. Then $NaHCO_3$ (0.12 g, 1.4 mmol) and FmocCl (0.25 g, 1.0 mmol) were added to the reaction mixture, and the resulting mixture was stirred for 4 h at rt. The reaction solution was extracted with CH_2Cl_2 (100 mL, four times). The organic layers were combined, dried over anhydrous Na_2SO_4, and concentrated under vacuum. The residue was purified by flash chromatography on silica gel ($MeOH/CH_2Cl_2$ = 30:1) to give **4j** (0.25 g, 89% yield) as a clear oil. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.75 (d, J = 7.5 Hz, 4H), 7.60 (d, J = 7.4 Hz, 4H), 7.38 (t, J = 7.4 Hz, 4H), 7.30 (t, J = 7.4 Hz, 4H), 5.67 (d, J = 3.1 Hz, 2H), 4.39 (s, 4H), 4.21 (t, J = 6.9 Hz, 2H), 4.02 (d, J = 3.5 Hz, 4H), 3.62−3.54 (m, 28H), 3.38 (dd, J = 10.2 Hz, 5.1 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.6, 144.0, 141.3, 129.3, 127.7, 127.1, 125.1, 112.0, 70.5, 70.3, 70.1, 69.5, 66.8, 66.5, 47.3, 40.9. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{50}H_{62}N_2O_{12}Na$: 905.4195; found: 905.4192.

General Procedure for Chlorotrifluoromethylthiolation. In a glovebox, a dry reaction tube was charged with 1-naphthalenylmethy-3-methylene-2-pyrrolidinone **1a** (0.2 mmol, 1.0 equiv), SCF_3 reagent **2a** (0.4 mmol, 2.0 equiv), Fe_2O_3 (10 mol %), and DMF (2.0 mL). Thionyl chloride (0.4 mmol, 2.0 equiv) was added to the reaction mixture at room temperature in the end. The mixture was stirred at 50 °C for 12 h. Then the mixture was quenched with H_2O (a few drops). The reaction mixture was concentrated in vacuo. The residue was directly subjected to silica gel flash chromatography (eluent: petroleum ether/ethyl acetate = 15/1) to afford the desired product **3a** in 85% yield.

*3-Chloro-1-(naphthalen-1-ylmethyl)-3-(((trifluoromethyl)thio)-methyl)pyrrolidin-2-one (**3a**).* The product (65.8 mg, 88% yield) was purified with silica gel chromatography (petroleum ether/ethyl acetate = 10/1) as a yellow solid (mp 68−69 °C). ^1H NMR (500 MHz, $CDCl_3$) δ = 8.02 (d, J = 7.9 Hz, 1H), 7.92−7.80 (m, 2H), 7.57−7.47 (m, 2H), 7.45−7.38 (m, 2H), 5.05 (d, J = 14.6 Hz, 1H), 4.87 (d, J = 14.6 Hz, 1H), 4.28 (d, J = 11.1 Hz, 1H), 3.91 (d, J = 11.1 Hz, 1H), 3.25 (dt, J = 9.9 Hz, 7.6 Hz, 1H), 3.19−3.07 (m, 1H), 2.64−2.49 (m, 1H), 2.27 (ddd, J = 14.5 Hz, 7.5 Hz, 2.7 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.1, 134.0, 131.5, 130.8, 129.8 (q, J = 309.9 Hz), 129.4, 128.8, 127.9, 127.0, 126.4, 125.2, 123.9, 58.2, 47.5, 46.0, 43.4, 28.1. ^{19}F NMR (471 MHz, $CDCl_3$) δ −39.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{17}H_{15}ClF_3NOSNa$: 396.0407; found: 396.0404.

*1-Benzyl-3-chloro-3-(((trifluoromethyl)thio)methyl)pyrrolidin-2-one (**3b**).* The product (45.3 mg, 70% yield) was purified with silica gel chromatography (petroleum ether/ethyl acetate = 10/1) as a white solid (mp 65−66 °C). ^1H NMR (500 MHz, $CDCl_3$) δ = 7.36−7.30 (m, 3H), 7.25 (d, J = 6.9 Hz, 2H), 4.52 (q, J = 14.7 Hz, 2H), 4.27 (d, J = 11.1 Hz, 1H), 3.94 (d, J = 11.1 Hz, 1H), 3.37 (dt, J = 9.8 Hz, 7.5 Hz, 1H), 3.32−3.25 (m, 1H), 2.69 (dt, J = 15.7 Hz, 8.0 Hz, 1H), 2.38 (ddd, J = 14.3 Hz, 7.6 Hz, 2.9 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.6, 135.3, 130.0 (q, J = 309.9 Hz), 129.0, 128.3, 128.1, 58.0, 47.7 (q, J = 1.6 Hz), 47.6, 43.6, 28.3 (q, J = 1.1 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −38.2. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{13}H_{13}ClF_3NOSNa$: 346.0251; found: 346.0255.

*3-Chloro-1-phenyl-3-(((trifluoromethyl)thio)methyl)pyrrolidin-2-one (**3c**).* The product (43.3 mg, 70% yield) was purified with silica gel chromatography (petroleum ether/ethyl acetate = 10/1) as a white solid (mp 27−29 °C). ^1H NMR (500 MHz, $CDCl_3$) δ = 7.54 (d, J = 7.8 Hz, 2H), 7.33 (t, J = 8.0 Hz, 2H), 7.15 (t, J = 7.4 Hz, 1H), 4.23 (d, J = 11.3 Hz, 1H), 3.96−3.90 (m, 2H), 3.82 (td, J = 9.2 Hz, 2.8 Hz, 1H), 2.82−2.76 (m, 1H), 2.43 (ddd, J = 14.2 Hz, 7.3 Hz, 2.6 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 167.6, 138.5, 129.8 (q, J = 309.9 Hz), 129.2, 125.9, 120.5, 59.0, 47.7 (q, J = 1.6 Hz), 45.7, 28.0. ^{19}F NMR (471 MHz, $CDCl_3$) δ −38.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{12}H_{11}ClF_3NOSNa$: 332.0094; found: 332.0104.

*3-Chloro-1-methyl-3-(((trifluoromethyl)thio)methyl)pyrrolidin-2-one (**3d**).* The product (37.1 mg, 75% yield) was purified with silica gel chromatography (petroleum ether/ethyl acetate = 4/1) as a yellow oil. ^1H NMR (500 MHz, $CDCl_3$) δ = 4.19 (d, J = 11.2 Hz, 1H), 3.92 (d, J = 11.1 Hz, 1H), 3.58−3.49 (m, 1H), 3.43 (td, J = 9.3 Hz, 3.4 Hz, 1H), 2.94 (s, 3H), 2.75−2.69 (m, 1H), 2.47 (ddd, J = 14.2 Hz, 7.8 Hz, 3.2 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.6, 130.0 (q, J = 309.9 Hz), 57.9, 47.9, 46.5, 30.6, 28.5. ^{19}F NMR (471 MHz, $CDCl_3$) δ −38.2. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_7H_9ClF_3NOSH$: 248.0118; found: 248.0120.

*1-Butyl-3-chloro-3-(((trifluoromethyl)thio)methyl)pyrrolidin-2-one (**3e**).* The product (41.7 mg, 72% yield) was purified with silica gel chromatography (petroleum ether/ethyl acetate = 5/1) as a yellow oil. ^1H NMR (500 MHz, $CDCl_3$) δ = 4.20 (d, J = 11.1 Hz, 1H), 3.92 (d, J = 11.1 Hz, 1H), 3.55−3.48 (m, 1H), 3.42 (td, J = 9.3 Hz, 3.2 Hz, 1H), 3.39−3.31 (m, 2H), 2.77−2.66 (m, 1H), 2.44 (ddd, J = 14.2 Hz, 7.6 Hz, 3.0 Hz, 1H), 1.58−1.51 (m, 2H), 1.34 (dd, J = 15.0 Hz, 7.5 Hz, 2H), 0.94 (t, J = 7.4 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.3, 130.0 (q, J = 309.9 Hz), 58.2, 47.8, 44.3, 43.4, 29.1, 28.5, 20.0, 13.8.

DOI: 10.1021/acs.joc.7b03261
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^{19}F NMR (471 MHz, $CDCl_3$) δ −38.3. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{10}H_{15}ClF_3NOSH$: 290.0588; found: 290.0586.

*2-Phenyl-2-chloroethyl(trifluoromethyl)sulfane (**3f**).* The product (41.7 mg, 72% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.40−7.33 (m, 5H), 5.03 (t, J = 7.5 Hz, 1H), 3.57 (dd, J = 14.2 Hz, 7.3 Hz, 1H), 3.43 (dd, J = 14.2 Hz, 7.7 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.8, 130.0 (q, J = 307.4 Hz), 129.4, 129.1, 127.3, 61.0, 38.7 (q, J = 1.9 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.0. HRMS (EI) m/z: [M] calcd for $C_9H_8ClF_3S$: 239.9987; found: 239.9990.

*(2-(2-Methoxyphenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3g**).* The product (30.3 mg, 56% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.44 (d, J = 7.6 Hz, 1H), 7.33 (t, J = 8.5 Hz, 1H), 7.00 (t, J = 7.5 Hz, 1H), 6.91 (d, J = 8.3 Hz, 1H), 5.55 (t, J = 7.3 Hz, 1H), 3.87 (s, 3H), 3.58 (dd, J = 14.1 Hz, 6.6 Hz, 1H), 3.48 (dd, J = 14.1 Hz, 8.0 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 156.6, 132.5 (q, J = 307.4 Hz), 130.4, 128.2, 126.9, 121.1, 111.1, 56.0, 55.7, 37.7 (q, J = 1.9 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.3. HRMS (EI) m/z: [M] calcd for $C_{10}H_{10}ClF_3OS$: 270.0093; found: 270.0098.

*(2-(2-Bromophenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3h**).* The product (33.2 mg, 52% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.58 (dd, J = 7.8 Hz, 3.8 Hz, 2H), 7.38 (t, J = 7.6 Hz, 1H), 7.24−7.19 (m, 1H), 5.62 (t, J = 6.9 Hz, 1H), 3.54 (dd, J = 14.3 Hz, 6.4 Hz, 1H), 3.45 (dd, J = 14.2 Hz, 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 137.9, 133.4, 130.7 (q, J = 307.4 Hz), 130.6, 128.7, 128.4, 123.3, 59. 5, 37.8. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.1. HRMS (EI) m/z: [M] calcd for $C_9H_7BrClF_3S$: 317.9092; found: 317.9096.

*(2-(3-Methoxyphenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3i**).* The product (47.1 mg, 87% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.29 (t, J = 7.9 Hz, 1H), 6.95 (d, J = 8.0 Hz, 1H), 6.92 (s, 1H), 6.88 (dd, J = 8.3 Hz, 2.5 Hz, 1H), 4.99 (t, J = 7.5 Hz, 1H), 3.80 (s, 3H), 3.55 (dd, J = 14.2 Hz, 7.4 Hz, 1H), 3.43 (dd, J = 14.2 Hz, 7.7 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 160.1, 140.3, 130.8 (q, J = 307.4 Hz), 130.2, 119.5, 114.7, 113.1, 60.9, 55.4, 38.6 (q, J = 1.9 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.2. HRMS (EI) m/z: [M] calcd for $C_{10}H_{10}ClF_3OS$: 270.0093; found: 270.0101.

*(2-(3-Chlorophenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3j**).* The product (46.8 mg, 85% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.39 (t, J = 1.8 Hz, 1H), 7.35−7.29 (m, 2H), 7.25 (dt, J = 7.0 Hz, 1.8 Hz, 1H), 4.97 (t, J = 7.5 Hz, 1H), 3.54 (dd, J = 14.3 Hz, 7.2 Hz, 1H), 3.39 (dd, J = 14.3 Hz, 7.9 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 140.7, 135.0, 130.7 (q, J = 307.4 Hz), 130.3, 129.6, 127.6, 125.6, 60.0, 38.5 (q, J = 1.9 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.3. HRMS (EI) m/z: [M] calcd for $C_9H_7Cl_2F_3S$: 273.9598; found: 273.9604.

*(2-(3-Bromophenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3k**).* The product (42.8 mg, 67% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.55 (s, 1H), 7.50 (d, J = 7.8 Hz, 1H), 7.32 (d, J = 7.6 Hz, 1H), 7.26 (t, J = 7.3 Hz, 1H), 4.97 (t, J = 7.5 Hz, 1H), 3.55 (dd, J = 14.3 Hz, 7.2 Hz, 1H), 3.40 (dd, J = 14.3 Hz, 7.8 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 140.9, 132.5, 130.7 (q, J = 307.4 Hz), 130.6, 130.5, 126.1, 123.1, 60.0, 38.5. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.2. HRMS (EI) m/z: [M] calcd for $C_9H_7BrClF_3S$: 317.9092; found: 317.9097.

*4-(1-Chloro-3,3,3-trifluoro-3-thioxo-3-propyl)phenyl Acetate (**3l**).* The product (53.8 mg, 90% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.40 (d, J = 8.6 Hz, 2H), 7.12 (d, J = 8.7 Hz, 2H), 5.03 (t, J = 7.5 Hz, 1H), 3.56 (dd, J = 14.3 Hz, 7.4 Hz, 1H), 3.41 (dd, J = 14.3 Hz, 7.6 Hz, 1H), 2.30 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 169.3, 151.3, 136.3, 130.8 (q, J = 307.4 Hz), 128.5, 122.3, 60.4, 38.7, 21.2. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.1. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{11}H_{10}ClF_3O_2SNa$: 320.9934; found: 320.9934.

*(2-(4-Methylphenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3m**).* The product (39.2 mg, 77% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.28−7.24 (m, 2H), 7.18 (d, J = 7.9 Hz, 2H), 5.01 (t, J = 7.6 Hz, 1H), 3.56 (dd, J = 14.1 Hz, 7.3 Hz, 1H), 3.42 (dd, J = 14.1 Hz, 7.9 Hz, 1H), 2.35 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.4, 135.9, 130.9 (q, J = 307.4 Hz), 129.8, 127.2, 60.9, 38.6 (q, J = 2.0 Hz), 21.3. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.3. HRMS (EI) m/z: [M] calcd for $C_{10}H_{10}ClF_3S$: 254.0144; found: 254.0151.

*(2-(4-Fluorophenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3n**).* The product (44.0 mg, 85% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.37 (dd, J = 8.4 Hz, 5.2 Hz, 2H), 7.08 (t, J = 8.5 Hz, 2H), 5.02 (t, J = 7.5 Hz, 1H), 3.57 (dd, J = 14.2 Hz, 7.0 Hz, 1H), 3.40 (dd, J = 14.2 Hz, 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 163.1 (d, J = 249.0 Hz), 134.7, 130.8 (q, J = 307.4 Hz), 129.3 (d, J = 8.3 Hz), 116.12 (d, J = 21.9 Hz), 60.1, 38.7. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.1, −114.9. HRMS (EI) m/z: [M] calcd for $C_9H_7ClF_4S$: 257.9893; found: 257.9899.

*(2-(4-Bromophenyl)-2-chloroethyl)(trifluoromethyl)sulfane (**3o**).* The product (50.0 mg, 78% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.53−7.50 (m, 2H), 7.27−7.24 (m, 2H), 4.98 (t, J = 7.5 Hz, 1H), 3.55 (dd, J = 14.3 Hz, 7.0 Hz, 1H), 3.38 (dd, J = 14.3 Hz, 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 137.8, 132.27, 130.7 (q, J = 307.4 Hz), 129.0, 123.4, 60.1, 38.4 (q, J = 1.8 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.1. HRMS (EI) m/z: [M] calcd for $C_9H_7BrClF_3S$: 317.9092; found: 317.9091.

*(2-Chloro-2-(naphthalen-1-yl)ethyl)(trifluoromethyl)sulfane (**3p**).* The product (46.5 mg, 80% yield) was purified with silica gel chromatography (petroleum ether) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 8.10 (d, J = 8.5 Hz, 1H), 7.89 (dd, J = 15.7 Hz, 8.2 Hz, 2H), 7.66 (d, J = 7.2 Hz, 1H), 7.61 (t, J = 7.6 Hz, 1H), 7.51 (dt, J = 22.1 Hz, 7.7 Hz, 2H), 5.89 (t, J = 7.2 Hz, 1H), 3.78−3.69 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 134.1, 134.1, 130.5, 130.9 (q, J = 307.4 Hz), 130.2, 129.4, 127.2, 126.4, 125.4, 125.1, 122.5, 57.5, 37.7 (q, J = 2.1 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.2. HRMS (EI) m/z: [M] calcd for $C_{13}H_{10}ClF_3S$: 290.0144; found: 290.0152.

*(2-Chloro-2-(naphthalen-2-yl)ethyl)(trifluoromethyl)sulfane (**3q**).* The product (48.8 mg, 84% yield) was purified with silica gel chromatography (petroleum ether) as a white solid (mp 54−57 °C). ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.88−7.81 (m, 4H), 7.50−7.52 (m, 3H), 5.21 (t, J = 7.5 Hz, 1H), 3.66 (dd, J = 14.2 Hz, 7.2 Hz, 1H), 3.54 (dd, J = 14.2 Hz, 7.9 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 135.9, 133.7, 133.1, 130.9 (q, J = 307.4 Hz), 129.3, 128.3, 127.9, 127.1, 127.0, 124.1, 61.3, 38.5. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.1. HRMS (EI) m/z: [M] calcd for $C_{13}H_{10}ClF_3S$: 290.0144; found: 290.0142.

*(1,4-Bis(benzyloxy)-3-chlorobutan-2-yl)(trifluoromethyl)sulfane (**5a**).* The product (79.4 mg, 98% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 100:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.29−7.21 (m, 10H), 4.60 (t, J = 10 Hz, 1H), 4.52−4.45 (m, 4H), 3.83 (ddd, J = 8.1 Hz, 5.9 Hz, 1.7 Hz, 1H), 3.80−3.75 (m, 1H), 3.73−3.70 (m, 2H), 3.67 (dd, J = 9.8 Hz, 5.8 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 137.57, 137.55, 130.9 (q, J = 307.4 Hz), 128.63, 128.61, 128.1, 128.0, 127.9, 73.6, 73.5, 70.9, 70.2, 57.4, 46.6. ^{19}F NMR (471 MHz, $CDCl_3$) δ −42.8. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{19}H_{20}ClF_3O_2SNa$: 427.0717; found: 427.0723.

*(3-Chloro-1,4-bis(naphthalen-1-ylmethoxy)butan-2-yl)-(trifluoromethyl)sulfane (**5b**).* The product (80.8 mg, 80% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 50:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 8.01−8.00 (m, 2H), 7.80 (dd, J = 6.2 Hz, 2.7 Hz, 2H), 7.77−7.75 (m, 4H), 7.47−7.42 (m, 4H), 7.37−7.34 (m, 4H), 4.94−4.83 (m, 4H), 4.57 (t, J = 6.8 Hz, 1H), 3.84−3.80 (m, 4H), 3.70 (dd, J = 10.0 Hz, 5.9 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 133.87, 133.85, 133.1, 133.0, 131.8, 130.9 (q, J = 307.4 Hz), 129.1, 129.0, 128.69, 128.65, 126.8, 126.7, 126.5, 126.4, 126.0, 125.3, 124.1, 124.0, 71.99, 71.95, 70.9, 70.1, 57.5, 46.7. ^{19}F NMR (471 MHz, $CDCl_3$) δ −42.9. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{27}H_{24}ClF_3O_2SNa$: 527.1030; found: 527.1034.

DOI: 10.1021/acs.joc.7b03261
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*(1,4-Dibutoxy-3-chlorobutan-2-yl)(trifluoromethyl)sulfane (**5c**).* The product (39.1 mg, 58% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 10:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.58 (t, J = 6.8 Hz, 1H), 3.82−3.78 (m, 2H), 3.74−3.72 (m, 2H), 3.68 (dd, J = 9.9 Hz, 5.8 Hz, 1H), 3.51−3.46 (m, 4H), 1.57−1.54 (m, 4H), 1.37 (ddd, J = 14.7 Hz, 7.4 Hz, 4.4 Hz, 4H), 0.92 (td, J = 7.4 Hz, 3.3 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ = 130.9 (q, J = 307.4 Hz), 71.4, 71.3, 70.7, 57.4, 46.5, 31.80, 31.77, 19.4, 19.3, 14.0. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.1. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{13}H_{24}ClF_3O_2SH$: 337.1210; found: 337.1223.

*11-Chloro-10-((trifluoromethyl)thio)-2,4,6,13,16,19-hexaoxaicosane (**5d**).* The product (57.5 mg, 67% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 5:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.64 (t, J = 7.0 Hz, 1H), 3.86 (dd, J = 12.3 Hz, 6.1 Hz, 2H), 3.83−3.75 (m, 3H), 3.72−3.60 (m, 12H), 3.55 (dd, J = 6.9 Hz, 4.2 Hz, 4H), 3.39 (s, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 130.85 (q, J = 307.4 Hz), 72.0, 71.2, 70.9, 70.8, 70.70, 70.68, 70.60, 70.57, 59.1, 57.2, 46.4. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.1. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{15}H_{28}ClF_3O_6SNa$: 451.1139; found: 451.1145.

*11-Chloro-1,20-diphenyl-10-((trifluoromethyl)thio)-2,4,6,13,16,19-hexaoxaicosane (**5e**).* The product (81.4 mg, 70% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 5:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.34 (d, J = 4.3 Hz, 8H), 7.30−7.27 (m, 2H), 4.63 (t, J = 7.0 Hz, 1H), 4.56 (s, 4H), 3.87−3.81 (m, 2H), 3.81−3.77 (m, 3H), 3.70−3.62 (m, 16H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.4, 130.9 (q, J = 307.4 Hz), 128.5, 127.9, 127.8, 73.4, 72.1, 71.3, 71.0, 70.87, 70.86, 70.7, 70.64, 69.59, 57.4, 46.4. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{27}H_{36}ClF_3O_6SNa$: 603.1765; found: 603.1753.

*1,16-Diazido-9-chloro-8-((trifluoromethyl)thio)-2,4,11,14-tetraoxahexadecane (**5f**).* The product (61.3 mg, 68% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 5:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.64 (t, J = 6.9 Hz, 1H), 3.90−3.86 (m, 2H), 3.84−3.75 (m, 3H), 3.73−3.66 (m, 12H), 3.39 (d, J = 4.2 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 130.9 (q, J = 307.4 Hz), 72.1, 71.3, 70.9, 70.8, 70.7, 70.6, 70.24, 70.22, 57.2, 50.8, 46.4. ^{19}F NMR (471 MHz, $CDCl_3$) δ −42.9. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{13}H_{22}ClF_3N_6O_4SNa$: 473.0956; found: 473.0965.

*15-Chloro-14-((trifluoromethyl)thio)-3,5,7,10,17,20,23,26-octaoxaoctacosane-1,28-diol (**5g**).* The product (61.9 mg, 58% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 1:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.63 (t, J = 6.7 Hz, 1H), 3.87−3.82 (m, 2H), 3.82−3.78 (m, 3H), 3.77−3.55 (m, 4H), 3.72−3.62 (m, 28H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 130.9 (q, J = 307.4 Hz), 72.1, 71.5, 71.2, 70.9, 70.8, 70.7, 70.62, 70.59, 57.3, 46.4, 42.8. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.0. HRMS (ESI) m/z: $[M + K]^+$ calcd for $C_{21}H_{40}ClF_3KO_{10}S$: 615.1614; found: 615.1350.

*17-Chloro-1,32-diphenyl-16-((trifluoromethyl)thio)-2,5,7,9,12,19,22,25,28,31-decaoxadotriacontane (**5h**).* The product (109.1 mg, 72% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 1:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.34 (d, J = 4.3 Hz, 8H), 7.28−7.26 (m, 2H), 4.62 (t, J = 7.0 Hz, 1H), 4.56 (s, 4H), 3.84 (t, J = 8.9 Hz, 2H), 3.81−3.74 (m, 3H), 3.68−3.62 (m, 32H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.3, 130.8 (q, J = 307.4 Hz), 128.4, 127.8, 127.6, 73.3, 72.0, 71.2, 70.8, 70.71, 70.69, 70.53, 70.51, 69.5, 57.2, 46.4. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{35}H_{52}ClF_3O_{10}SNa$: 779.2814; found: 779.2818.

*1,28-Diazido-15-chloro-14-((trifluoromethyl)thio)-3,5,7,10,17,20,23,26-octaoxaoctacosane (**5i**).* The product (84.0 mg, 67% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 1:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.63 (t, J = 6.6 Hz, 1H), 3.87−3.84 (m, 2H), 3.81−3.77 (m, 3H), 3.67−3.64 (m, 28H), 3.40−3.38 (m, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 130.9 (q, J = 307.4 Hz), 72.0, 71.2, 70.9, 70.80, 70.78, 70.75, 70.58, 70.55, 70.1, 57.3, 50.8, 46.4. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{21}H_{38}ClF_3N_6O_8SNa$: 649.2005; found: 649.2008.

*Bis((9H-fluoren-9-yl)methyl)(15-chloro-14-((trifluoromethyl)thio)-3,5,7,10,17,20,23,26-octaoxaoctacosane-1,28-diyl)dicarbamate (**5j**).* The product (163.1 mg, 80% yield) was purified with silica gel chromatography ($MeOH/CH_2Cl_2$ = 30:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.76 (d, J = 7.5 Hz, 4H), 7.60 (d, J = 7.1 Hz, 4H), 7.39 (t, J = 7.4 Hz, 4H), 7.31 (t, J = 7.3 Hz, 4H), 5.41 (s, 2H), 4.60 (d, J = 5.8 Hz, 1H), 4.40 (d, J = 6.2 Hz, 4H), 4.22 (d, J = 6.1 Hz, 2H), 3.87−3.72 (m, 5H), 3.69−3.53 (m, 28H), 3.39 (d, J = 4.4 Hz, 4H). ^{13}C NMR (126 MHz, CDCl3) δ 161.5, 156.7, 144.1, 141.4, 130.9 (q, J = 307.4 Hz), 127.8, 127.2, 125.2, 120.1, 72.0, 71.2, 70.84, 70.75, 70.67, 70.60, 70.56, 70.5, 70.4, 70.3, 70.2, 69.8, 66.7, 57.3, 47.4, 41.1, 37.9. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{51}H_{62}ClF_3N_2O_{12}SNa$: 1041.3556; found: 1041.3554.

*Di-tert-butyl 2,2′-((2-Chloro-3-((trifluoromethyl)thio)butane-1,4-diyl)bis(oxy))diacetate (**5k**).* The product (66.1 mg, 73% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 5:1) as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 4.72 (t, J = 6.9 Hz, 1H), 4.08−3.97 (m, 4H), 3.93−3.86 (m, 5H), 1.48 (s, 18H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 169.2, 169.1, 130.8 (q, J = 307.4 Hz), 82.13, 82.05, 72.2, 71.4, 69.3, 69.2, 57.3, 46.5, 28.2. ^{19}F NMR (471 MHz, $CDCl_3$) δ −43.1. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{17}H_{28}ClF_3O_6SNa$: 475.1139; found: 475.1141.

*(1-Chloro-1-phenylpropan-2-yl)(trifluoromethyl)sulfane (**5l**).* The product (25.4 mg, 50% yield) was purified with silica gel chromatography (petroleum ether) as a mixture of diasteroisomers and regioisomers that cannot be isolated. ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.44−7.33 (m, 5H). 5.14 (d, J = 4.7 Hz, 1H), 3.80 (qd, J = 7.0 Hz, 4.8 Hz, 1H). 1.50 (d, J = 7.0 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 136.8, 130.9 (q, J = 307.4 Hz), 129.0, 128.9, 128.8, 128.4, 127.5, 65.6, 48.0 (q, J = 1.2 Hz), 18.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ −42.8. HRMS (EI) m/z: [M] calcd for $C_{10}H_{10}ClF_3S$: 254.0144; found: 254.0140.

*(6-Chlorodecan-5-yl)(trifluoromethyl)sulfane (**5m**).* The product (41.4 mg, 75% yield) was purified with silica gel chromatography (petroleum ether) as the mixture of diasteroisomers that cannot be isolated. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 4.20−4.14 (m, 1H), 3.30−3.24 (m, 1H), 1.88−1.75 (m, 3H), 1.60 (dddd, J = 16.9 Hz, 15.0 Hz, 6.6 Hz, 3.2 Hz, 3H), 1.46−1.26 (m, 6H), 0.93 (td, J = 7.2 Hz, 2.0 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 131.2 (q, J = 306.2 Hz), 65.3, 52.1, 34.5, 32.5, 29.3, 29.1, 22.3, 22.2, 14.03, 14.00. ^{19}F NMR (376 MHz, $CDCl_3$) δ −42.9. HRMS (EI) m/z: [M] calcd for $C_{11}H_{20}ClF_3S$: 276.0926; found: 276.0930.

*(2-Azido-2-(naphthalen-1-yl)ethyl)(trifluoromethyl)sulfane (**6**).* A solution of **3p** (0.1 mmol, 29.1 mg) and sodium azide (0.15 mmol, 10.0 mg) in 1 mL of DMF was heated to 80 °C, and the mixture was stirred for 8 h until **3p** was completely transformed. The mixture was cooled and concentrated in vacuo. The residue was directly subjected to silica gel flash chromatography (petroleum ether) to afford the desired product **6** (28.2 mg, 95%). ^{1}H NMR (500 MHz, $CDCl_3$) δ = 8.03 (d, J = 8.4 Hz, 1H), 7.90 (dd, J = 20.3 Hz, 8.1 Hz, 2H), 7.57−7.50 (m, 4H), 5.51 (dd, J = 9.5 Hz, 4.3 Hz, 1H), 3.41 (dd, J = 14.3 Hz, 4.4 Hz, 1H), 3.26 (dd, J = 14.1 Hz, 9.7 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 134.2, 133.09, 131.10 (q, J = 307.4 Hz), 130.4, 129.9, 129.5, 127.3, 126.4, 125.5, 124.8, 122.3, 62.9, 35.8. ^{19}F NMR (471 MHz, $CDCl_3$) δ −44.0. HRMS (EI) m/z: [M] calcd for $C_{13}H_{10}F_3N_3S$: 297.0548; found: 297.0551.

*(2-(Naphthalen-1-yl)-2-thiocyanatoethyl)(trifluoromethyl)-sulfane (**7**).* A solution of **3p** (0.1 mmol, 29.1 mg) and KSCN (0.15 mmol, 14.4 mg) in 1 mL of DMF was heated to 80 °C, and the mixture was stirred for 8 h until **3p** was completely transformed. The mixture was cooled and concentrated in vacuo. The residue was directly subjected to silica gel flash chromatography (petroleum ether/AcOEt = 30:1) to afford the desired product **7** (28.2 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.00 (d, J = 8.5 Hz, 1H), 7.96−7.92 (m, 2H), 7.68−7.64 (m, 1H), 7.60 (dd, J = 11.1 Hz, 3.9 Hz, 1H), 7.56−7.51 (m, 2H), 5.41 (t, J = 7.9 Hz, 1H), 3.91 (d, J = 7.8 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 134.3, 130.9, 130.5 (q, J = 140.39 Hz), 129.7, 127.7, 126.8, 125.4, 121.9, 110.4, 34.7. ^{19}F NMR (471 MHz,

DOI: 10.1021/acs.joc.7b03261
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$CDCl_3$) δ −44.1. HRMS (ESI) m/z: [M + Na]$^+$ calcd for $C_{14}H_{10}F_3NS_2Na$: 336.0099; found: 336.0102.

*(E)-(2-(Naphthalen-1-yl)vinyl)(trifluoromethyl)sulfane (**8**).*[26] The solution of **3p** (0.1 mmol, 29.1 mg) in 1 mL of piperidine was stirred 8 h at 50 °C. The mixture was cooled and concentrated in vacuo. The residue was directly subjected to silica gel flash chromatography (petroleum ether) to afford the desired product **8** (22.9 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.05 (d, J = 8.2 Hz, 1H), 7.86 (dd, J = 8.3 Hz, 6.5 Hz, 2H), 7.76 (d, J = 15.1 Hz, 1H), 7.59−7.53 (m, 3H), 7.53−7.46 (m, 3H), 6.80 (d, J = 15.1 Hz, 1H). ^{19}F NMR (471 MHz, $CDCl_3$) δ −45.8.

*S,S′-(1-(Naphthalen-1-yl)ethane-1,2-diyl) Diethanethioate (**9**).* A solution of **3p** (0.1 mmol, 29.1 mg) and potassium thioacetate (0.2 mmol, 22.8 mg) in 1 mL of DMF was heated to 80 °C, and the mixture was stirred for 8 h until **3p** was completely transformed. The mixture was cooled and concentrated in vacuo. The residue was directly subjected to silica gel flash chromatography (petroleum ether/AcOEt = 30:1) to afford the desired product **9** (27.4 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.10 (d, J = 8.5 Hz, 1H), 7.86 (d, J = 7.6 Hz, 1H), 7.79 (d, J = 8.0 Hz, 1H), 7.57 (ddd, J = 8.4 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.54−7.46 (m, 2H), 7.46−7.41 (m, 1H), 5.59 (s, 1H), 3.70 (dd, J = 13.6 Hz, 8.2 Hz, 1H), 3.62 (dd, J = 13.6 Hz, 7.5 Hz, 1H), 2.35 (s, 3H), 2.28 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 194.9, 194.4, 135.1, 134.1, 130.9, 129.1, 128.9, 126.8, 126.1, 125.3, 123.2, 34.7, 30.6, 30.4. HRMS (ESI) m/z: [M + Na]$^+$ calcd for $C_{16}H_{16}O_2S_2Na$: 327.0484; found: 327.0479.

*(Z)-(5-Chloro-2,5-diphenylpent-2-en-1-yl)(trifluoromethyl)sulfane (**11**).* The product (25.0 mg, 37% yield) was purified with silica gel chromatography (petroleum ether/EtOAc = 30:1) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.43−7.26 (m, 10H), 5.91 (t, J = 7.3 Hz, 1H), 4.97 (dd, J = 7.9 Hz, 6.3 Hz, 1H), 3.96−3.86 (m, 2H), 3.12−2.93 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 141.0, 140.2, 135.8, 130.7 (q, J = 307.4 Hz), 129.2, 128.9, 128.7, 128.1, 127.10, 127.07, 126.4, 62.5, 39.4, 29.6 (q, J = 2.3 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ −45.0. HRMS (EI) m/z: [M] calcd for $C_{18}H_{16}ClF_3S$: 356.0613; found: 356.0617.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.7b03261.

Copies of ^{1}H/^{19}F/^{13}C NMR and MS/HRMS spectra (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We gratefully acknowledge financial support from the National Key Research and Development Program of China (grant no. 2016YFC1304704), the National Natural Science Foundation of China (grant nos. 21402144, 21372181 and 21572168), and the Natural Science Foundation of Hubei Province (grant no. 2017CFA024).

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