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Development of Odorless Thiols and Sulfides and Their Applications to Organic Synthesis

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Summary. Development of new odorless thiols (dodecanethiol, 4-*n*-heptylphenylmethanethiol, 4-trimethylsilylphenylmethanethiol, 4-trimethylsilylbenzenethiol) and an odorless sulfide (1-methylsulfanyldodecane) and their applications to dealkylation, *Michael* addition, *Swern* oxidation, and *Corey-Kim* oxidation are described.

Keywords. Dealkylation; *Michael* addition; Alcohols; *Swern* oxidation; *Corey-Kim* oxidation.

Introduction

Thiols and sulfides are fundamental and important functional groups in organic chemistry, and the literature contains ample reports on the organic and bioorganic chemistry of this group [1]. Among them, benzenethiol is a main component for the syntheses of heterocycles containing a sulfur atom. Commonly used thiols and sulfides like ethanethiol, benzyl mercaptan, benzenethiol, and dimethyl sulfide have malodor making their use difficult and unpleasant. The problem becomes even worse in industry where these malodorous reagents are used on a large scale. In an application of green chemistry, odorless substitutes are therefore always required for the prevention of environmental pollution and stress of the researchers working with them. In order to improve this drawback, an odorless bulky thiol [2] and an odorless sodium dithiocarboxylate [3] were reported for demethylations of phenyl methyl ethers and methyl phosphates. Based on our knowledge of a chiral 1,3-mercapto alcohol used in a novel tandem *Michael* addition – *Meerwein-Ponndorf-Verley* reduction [4], we developed a chiral odorless synthetic equivalent of hydrogen sulfide for the *Michael* addition [5]. Recently, odorless versions of the *Corey-Kim* oxidation [6] and the *Swern* oxidation [7, 8] have been published using odorless substitutes for dimethyl sulfide. We report herein the development of new odorless thiols and sulfides to replace the usual foul-smelling ones, and their

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applications in organic synthesis, *i.e.*, dealkylation, *Michael* addition, *Swern* oxidation, and *Corey-Kim* oxidation.

Results and Discussions

*The Exploitation of Odorless Dod-SH (**1**) and 4-n-Heptylphenylmethanethiol (**2**)* [9]

Because the monoterpene mercapto alcohol, 10-mercaptoisoborneol, has not a foul smell, we planned to test the odor of a number of alkanethiols. The relative odor index of these thiols compared to the foul-smelling ethanethiol as perceived by the human nose of two test subjects is listed in Table 1.

The odor of a thiol depends virtually entirely on its purity, *i.e.*, 1-hexadecanethiol purified by HPLC on a GPC column was found to be almost odorless, while the commercial 1-hexadecanethiol had essentially the same odor as indicated in a chemical catalog. Therefore, purification of all these thiols was done on HPLC using a GPC column before analyzing their respective odors. Among the alkanethiols, 1-dodecanethiol (*Dod*-SH, **1**) was found to be odorless, while lower carbon-chain thiols were found to be malodorous. These facts suggest that the foul smell of thiol toward the human olfactory cell is related to the length of its carbon-chain.

We next examined the odor of benzyl mercaptans having an alkyl chain at their *para*-position. Results of the odor testing of various thiols are shown in Table 2.

Table 1. Odor scale for alkanethiols

Entry	Thiols	Carbon atoms in chain	Bp/°C[a]	Odor scale[b]	
				A	B
1	CH_3CH_2SH	2	35	5	5
2	$CH_3(CH_2)_2SH$	3	67–68	5	5
3	$CH_3(CH_2)_3SH$	4	98	5	4
4	$CH_3(CH_2)_4SH$	5	126	4	3
5	$CH_3(CH_2)_5SH$	6	150–154	3	3
6	$CH_3(CH_2)_6SH$	7	173–176	4	3
7	$CH_3(CH_2)_7SH$	8	197–200	2	1
8	$CH_3(CH_2)_8SH$	9	220	2	1
9	$CH_3(CH_2)_9SH$	10	114/13 mm Hg	1	1
10	$CH_3(CH_2)_{10}SH$	11	103–104/3 mm Hg[c]	1	0
11	$CH_3(CH_2)_{11}SH$ (**1**)	12	266–283	0	0
12	$CH_3(CH_2)_{13}SH$	14	298–320 (mp 7)[c]	0	1
13	$CH_3(CH_2)_{14}SH$	15	125–128/0.1 mm Hg[d]	0	0
14	$CH_3(CH_2)_{15}SH$	16	184–191/7 mm Hg (mp 18–20)	0	0

[a] Cited from the Aldrich chemical catalog unless otherwise noted; [b] odor scale: foul-smelling 5 to odorless 0 by the human nose of two test subjects A and B; [c] cited from "Dictionary of Organic Compounds" 2nd Ed., 1989, Koudansya, Tokyo; [d] experimental data

Table 2. Odor scale for benzylic mercaptans

Entry	Thiols	Odor scale[a]	
		A	B
1	*Ph*CH$_2$SH	5	5
2	4-*t-BuPh*CH$_2$SH	1	1
3	4-*n-BuPh*CH$_2$SH	2	1
4	4-*n-PentPh*CH$_2$SH	2	1
5	4-*n-HexPh*CH$_2$SH	0	1
6	4-*n-HeptPh*CH$_2$SH (**2**)	0	0
7	4-*n-OctPh*CH$_2$SH	1	0
8	4-*n-NonPh*CH$_2$SH	1	1

[a] Odor scale: foul-smelling 5 to odorless 0 by the human nose of two test subjects A and B

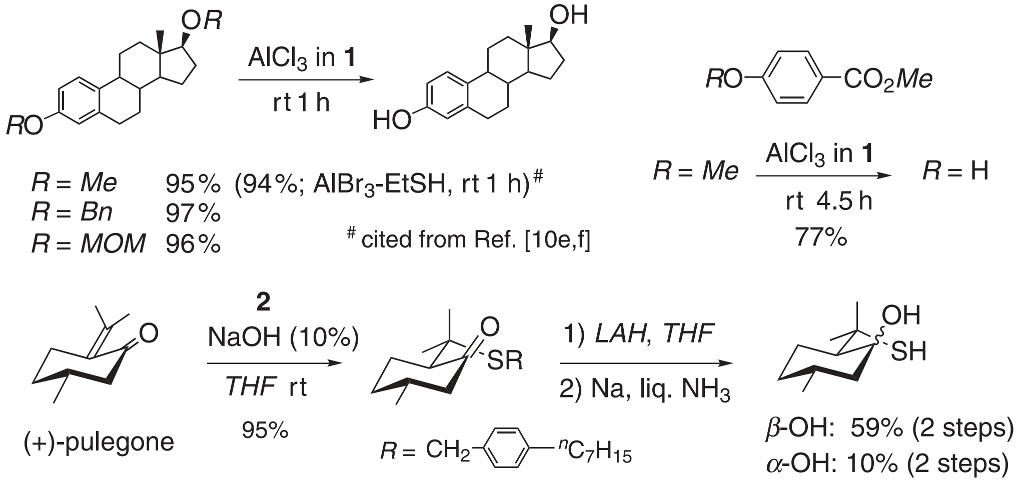


Fig. 1. Synthetic applications of odorless thiols **1** and **2**

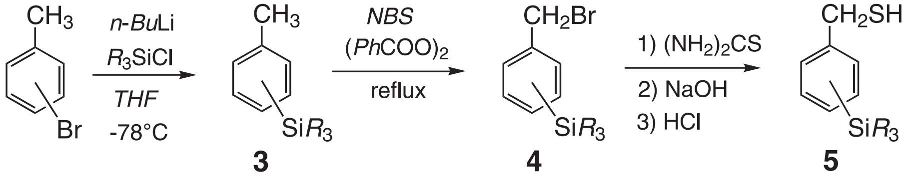
4-*n*-Heptylphenylmethanethiol (**2**) was chosen as the odorless substitute for benzyl mercaptan.

Some applications using odorless **1** and 4-*n*-heptylphenylmethanethiol (**2**) are shown in Fig. 1. Previously, we developed useful reagent systems (hard *Lewis* acid–thiol) for the demethylation of aliphatic and aromatic methyl ethers [10]. The yields of the parent alcohols and phenols from methyl, benzyl, and *MOM* ethers using aluminum chloride and **1** were very high, similar to those using the previous reagent system. The selective demethylation of a phenolic methyl ether in the presence of methyl ester was observed using the new reagent system. We have also demonstrated that the odorless **2** can be used instead of the parent benzyl mercaptan in the *Michael* addition of a thiol to an α,β-unsaturated ketone. Reductive cleavage of the benzylic carbon–sulfur bond with sodium metal in liquid ammonia gave the 1,3-mercapto alcohols in good yields.

The Exploitation of Odorless TMSBM and TMSBT [11]

The odorless benzyl mercaptan **2** could not be used to introduce a benzylthio group because removal of the heptyl group on the benzene ring proved to be difficult. Therefore, we developed new odorless thiols, which possessed a removable substituent on the phenyl and the benzyl groups. During our search for odorless thiols, we found that the 4-*tert*-butylphenylmethanethiol did not possess the odor of a thiol but rather that of an alcohol (Table 2, Entry 2). We therefore envisioned introducing a more bulky trialkylsilyl group onto the benzene ring that would reduce the smell of the parent benzenethiol and benzyl mercaptan, if indeed the olfactory sense of the human nose recognizes the odor of a compound by its steric bulkiness. Protodesilylation [12] would permit the introduction of a phenylthio or benzylthio group into the substrates under the odorless reaction conditions.

The syntheses and odor scales of trialkylsilylphenylmethanethiols **5** are shown in Table 3. The silylated benzyl mercaptans have considerably less odor than the parent benzyl mercaptan and slightly less than *tert*-butylphenylmethanethiol. The presence of a propyl group in the trialkylsilyl unit seems to cause a stronger thiol odor. Trimethylsilyl and triethylsilyl substituted products were found to have a very faint odor and in some cases were virtually odorless, regardless of the position of

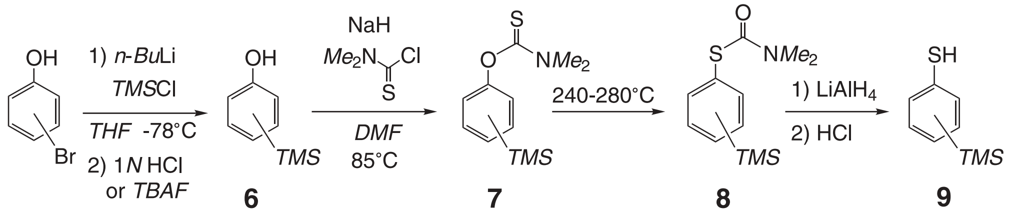


Scheme 1

Table 3. Odor scales of trialkylsilylphenylmethanethiols **5**

	Substrate	R_3SiCl	Yield/%			Odor scale[a]	
		R	**3**	**4**	**5**	A	B
a	*para*	*Me*	93	75	71	0	1
b	*meta*	*Me*	80	87	56	1	1
c	*ortho*	*Me*	67	61	53	1	0
d	*para*	*Et*	61	78	98	1	1
e	*meta*	*Et*	66	100	89	0	1
f	*ortho*	*Et*	100	79	94	0	1
g	*para*	*Pr*	60	90	97	1	2
h	*meta*	*Pr*	97	94	64	2	2
i	*ortho*	*Pr*	100	64	72	1	1
	PhCH_2SH[b]					5	5
	4-*t*-*BuPh*CH_2SH[b]					1	1

[a] Odor scale: foul-smelling 5 to odorless 0 by the human nose of two test subjects A and B; [b] cited from Table 2

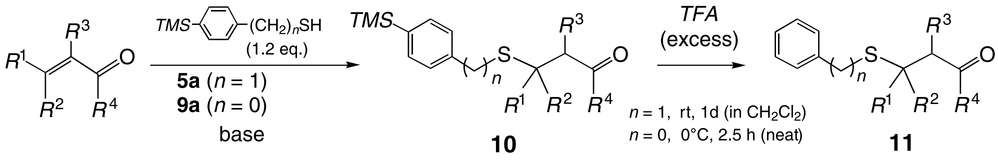


Scheme 2

Table 4. Odor scales of trimethylsilylbenzenethiols **9**

Entry	Substrate	Yield/%				Odor scale[a]	
		6	**7**	**8**	**9**	A	B
a	*para*	78	100	82	71	1	1
b	*meta*	90	100	53	83	1	1
c	*ortho*	89[b]	60	30	84	0	1
	*cf. Ph*SH					5	5
	*4-t-BuPh*SH					2	2

[a] Odor scale: foul-smelling 5 to odorless 0 by the human nose of two test subjects A and B; [b] treatment with *TBAF* was required for the cleavage of O-TMS bond, overall yield



Scheme 3

Table 5. *Michael* additions of **5a** and **9a** and protodesilylation

Entry	α,β-Unsat. carb. compd.				Thiol	Base (amount)	Solv.[a]	Temp.	Time	Yield/%	
	R^1	R^2	R^3	R^4	n					**10**	**11**
1	H	H	H	O*Et*	1	*TBAF* (0.2 eq)	*THF*	rt	0.5 h	100	88
2	H	H	H	O*Et*	0	Et_3N (0.1 eq)	*PE*	0°C-rt	2.5 d	100	100
3	H	H	*Me*	O*Et*	1	*TBAF* (0.2 eq)	*THF*	rt	0.5 h	95	90
4	H	H	*Me*	O*Et*	0	*DBU* (1.2 eq)	*PE*	rt	0.5 h	57	100
5	*Me*	H	H	O*Et*	1	*TBAF* (0.2 eq)	*THF*	rt	0.5 h	98	100
6	*Me*	H	H	O*Et*	0	Et_3N (0.1 eq)	*PE*	50°C	2 d	91	85
7	*Me*	*Me*	H	O*Et*	1	*TBAF* (0.2 eq)	*THF*	rt	20 h	71	53
8	*Me*	*Me*	H	O*Et*	0	*DBU* (1.2 eq)	*PE*	rt	1 d	n.r.	–
9	*Me*	H	H	*Et*	1	*TBAF* (0.2 eq)	*THF*	rt	0.5 h	95	97
10	*Me*	H	H	*Et*	0	Et_3N (1.2 eq)	*PE*	rt	6 h	100	100

[a] *THF*: tetrahydrofuran, *PE*: petroleum ether

the substituent on the benzene ring. 4-Trimethylsilylphenylmethanethiol (*TMSBM*, **5a**) [18] was chosen as a representative for silylated benzyl mercaptans.

Next we applied this knowledge of the odor reducing effect of the *TMS* group to benzenethiols. The syntheses and odor scales of trimethylsilylbenzenethiols **9** are summarized in Table 4. *Ortho*-, *meta*-, and *para*-bromophenols were transformed into the trimethylsilylbenzenethiols **9** by silylation, *N,N*-dimethylaminothiocarbamoylation, the *Newman-Kwart* rearrangement [13], and reduction. All of the trimethylsilylbenzenethiols **9** prepared had a faint odor or none at all. We chose 4-trimethylsilylbenzenethiol (*TMSBT*, **9a**) [19] as a representative for trimethylsilylbenzenethiols. The trimethylsilyl group on the substituted benzenethiols had a remarkable effect in reducing the foul smell of the parent benzenethiol.

In order to test the ability of **5a** and **9a** as odorless substitutes for the parent thiols, we demonstrated the *Michael* addition of α,β-unsaturated carbonyl compounds and protodesilylation of the *Michael* adducts. The results are shown in Table 5. Tetrabutylammonium fluoride (*TBAF*) in *THF* successfully catalyzed the *Michael* addition of **5a** (odd entries), whereas triethylamine or *DBU* in petroleum ether catalyzed the reaction of **9a** (even entries). The efficiency of the *Michael* addition with α,β-unsaturated carbonyl compounds was dependent on the nucleophilicity of the thiols. A longer reaction time was necessary with **9a** than with **5a**. The β-substituents on the α,β-unsaturated carbonyl compounds significantly retarded the reaction of **5a** (Entry 7). Furthermore, the reaction with **9a** did not proceed even under prolonged reaction time (Entry 8). Protodesilylation of the *Michael* adducts with trifluoroacetic acid [12b] permitted the introduction of the benzylthio and phenylthio groups under odorless reaction conditions.

New Odorless Swern and Corey-Kim Oxidations Utilizing Dod-S-Me [14]

The *Swern* oxidation (*DMSO*-oxalyl chloride) [15] is the most commonly used for oxidation of primary or secondary alcohols to aldehydes or ketones. Among its many advantages are mild conditions, stability of acid sensitive functional groups, no epimerization of the α-carbon of the carbonyl group, easy work-up, gaseous byproducts (carbon dioxide and carbon monoxide), and rapid reaction rate [16].

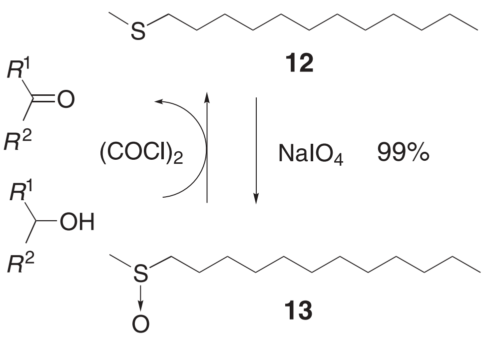


Fig. 2. A new odorless *Swern* oxidation

Nevertheless, one important drawback is the foul odor of the volatile dimethyl sulfide produced, which is regulated by the offensive odor control law. From an environmental standpoint, the need for odorless substitutes for foul-smelling molecules like dimethyl sulfide is therefore great.

1-Methylsulfanyldodecane (*Dod*-S-Me, **12**) synthesized from odorless *Dod*-SH was found to be odorless, whereas the low alkyl methyl sulfides were malodorous. We developed a new odorless *Swern* oxidation using the corresponding sulfoxide (*Dod*-S(O)-Me, **13**), as shown in Fig. 2.

The optimized reaction conditions for the new odorless *Swern* oxidation using **12** afforded high yields of the products (Table 6).

Table 6. Odorless *Swern* oxidation of alcohols using **13**

Substrate	Conditions (temp. and time after Et_3N addition)	Yield/%[a]	
		Aldehyde or ketone (lit.)[b]	Recovery of **12**
benzhydrol	−60°C ~ −40°C (3.33 h) −40°C ~ rt (1 h)	95 (98)	100
benzoin	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	91 (95)	94
2-bromophenylmethanol	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	95	95
cinnamyl alcohol	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	93 (98)	93
geraniol	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	93 (95)	89
1-adamantanemethanol	−60°C ~ −40°C (5 h) −40°C ~ rt (1 h)	93 (99)	99
(1*S*,2*R*,4*S*)-borneol	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	91 (95)	91
2-octanol	−60°C ~ −40°C (2 h) −40°C ~ rt (40 min)	81 (98)	95

[a] Isolated yield; [b] See Ref. [16c]

Table 7. Odorless *Corey-Kim* oxidation of alcohols using **12**

Alcohols $\xrightarrow[Et_3N\ (5\ \text{equiv.}),\ -40°\text{C}\ (14\ \text{h})]{NCS\ (3\ \text{equiv.}),\ \mathbf{12}\ (3\ \text{equiv.})}$ Aldehyes or ketones	Yield/%[a]	
	in CH_2Cl_2	in toluene
benzhydrol	95	98
benzoin	99	–[b]
cinnamyl alcohol	91	90
3,5-bis(benzyloxy)-4-methoxyphenylmethanol	99	95
testosterone	91	97

[a] Isolated yields; [b] the starting material was insoluble

The other oxidation of alcohols using dimethyl sulfide and *N*-chlorosuccinimide is known as the *Corey-Kim* oxidation [17]. Instead of using dimethyl sulfide, we applied **12** to this oxidation. The results of the new odorless *Corey-Kim* oxidation are compiled in Table 7. The yields of the products were excellent.

Conclusion

We were able to provide new *odorless thiols* **1**, **2**, **5a**, **9a**, and an *odorless sulfide* **12**, which were applied successfully to dealkylation, *Michael* addition, *Swern* oxidation, and *Corey-Kim* oxidation. These new odorless methods should replace the classical reactions. We believe that the odorless feature of these new methods is important for green chemistry as well as for synthetic organic chemistry in general.

Experimental

Melting points were taken on a micro hot-stage apparatus (Yanagimoto) and were uncorrected. Infrared (IR) spectra were recorded on a JASCO IR-810 or a Shimadzu FTIR-8300 diffraction grating infrared spectrophotometer and ^{1}H NMR spectra were obtained on a JEOL JNM-AL300 or a Varian Unity INOVA-400 spectrometer with tetramethylsilane as an internal standard. Mass spectra (MS) were determined on a JEOL JMS-SX 102A QQ or a JEOL JMS-GC-mate mass spectrometer. Combustion analysis was done on a Perkin Elmer Series II CHNS/O Analyzer 2400. Their results agreed favourably with calculated values. Wakogel C-200 (silica gel) (100–200 mesh, Wako) was used for open column chromatography. Flash column chromatography was performed with Silica Gel 60 N (Kanto Chemical Co., Inc.). Kieselgel 60 F-254 plates (Merck) were used for thin layer chromatography (TLC). When necessary, compounds were further purified by a recycle HPLC (JAI LC-908) on GPC column (JAIGEL 1H and 2H) after purification on silica gel or distillation.

1-Dodecanethiol (**1**) is available from Sigma-Aldrich Fine Chemicals Co. Ltd., or Wako Pure Chemical Industries, Ltd., but distillation is required for getting pure odorless compound for use. Dodecyl methyl sulfide (**12**) is also available from Pfaltz and Bauer Chemicals Co. Ltd. or Lancaster Co. Ltd. Dodecyl methyl sulfoxide (**13**) is now available from Wako Pure Chemical Industries, Ltd. Tetrahydrofuran (*THF*) and ether were distilled from sodium benzophenone ketyl, and CH_2Cl_2 was distilled from CaH_2 after ten washings with H_2O to remove methanol contaminants. *N,N*-Dimethylformamide (*DMF*) was also distilled from CaH_2 before use.

*Preparation of 4-n-Heptylphenylmethanethiol (**2**)*

To an ether (100 cm^3) suspension of 234 mg of $CuBr \cdot Me_2S$ (1.14 mmol, 0.6 equiv) and 500 mg of α,α'-dibromo-*p*-xylene (1.89 mmol) a *THF* solution (3 cm^3) of *n*-hexylmagnesium bromide (prepared from *n*-hexyl bromide (2.84 mmol, 1.5 equiv) and Mg metal by the standard method) was added dropwise over 10 min under nitrogen atmosphere at 0°C, and the reaction mixture was stirred for 6 h at the same temperature. The reaction mixture was poured into 20 cm^3 of cool 1 *N* HCl, and was extracted with ether (2×40 cm^3). The organic layer was washed with brine, dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Purification of the crude product by silica gel column chromatography using hexane as eluent gave 213 mg of 4-*n*-heptylphenylmethyl bromide (41%). ^{1}H NMR ($CDCl_3$, 400 MHz): $\delta = 0.87$ (t, $J = 6.80$ Hz, CH_3), 1.23–1.34 [m, $(CH_2)_4$], 1.56–1.65 (m, CH_2), 2.58 (t, $J = 7.60$ Hz, $ArCH_2$), 4.49 (s, CH_2Br), 7.14 (d, 2H, $J = 8.05$ Hz, ArH); MS (70 eV): $m/z = 270$ ($M^+ + 2$, 2.7), 268 (M^+, 2.5), 190 (16), 189 (100); HRMS: calcd. for $C_{14}H_{21}Br$ (M^+): 268.0826, found: 268.0822.

A mixture of 212 mg of 4-*n*-heptylphenylmethyl bromide (0.79 mmol) and 60 mg of thiourea (0.79 mmol) in 2 cm^3 of ethanol was refluxed for 14 h. The reaction mixture was cooled and diluted with 5 cm^3 of ether to precipitate the thiouronium salt. The 221 mg of thiouronium salt (81%) were filtered off. White solid; mp 164.5–165.0°C; MS (70 eV): $m/z = 265$ [$(M^+ + 1) - 80$, 2.6], 264 ($M^+ - 80$, 27), 231 (12), 190 (16), 189 (100), 105 (50); HRMS: calcd. for $C_{15}H_{24}N_2S$ (M^+): 264.1660, found: 264.1663.

A mixture of 221 mg of thiouronium salt, 6 cm^3 of a 6% NaOH solution, and 2 cm^3 of ethanol was refluxed with stirring for 3 h. The reaction mixture was cooled and acidified with 1 *N* HCl. The reaction mixture was extracted with ether ($2 \times 20\,cm^3$). The combined ethereal layer was washed with brine, dried ($MgSO_4$), filtered, and the solvent was evaporated under reduced pressure to give 124 mg of **2** (87%) as a colorless oil. ^1H NMR ($CDCl_3$, 400 MHz): $\delta = 0.88$ (t, $J = 6.95$ Hz, CH_3), 1.24–1.35 [m, $(CH_2)_4$], 1.57–1.64 (m, CH_2), 1.74 (t, $J = 7.50$ Hz, SH), 2.58 (t, $J = 7.58$ Hz, $ArCH_2$), 3.72 (d, $J = 7.50$ Hz, CH_2S), 7.13 (d, 2H, $J = 8.05$ Hz, ArH), 7.23 (d, 2H, $J = 8.05$ Hz, ArH); IR ($CHCl_3$): $\bar{\nu} = 3009$, 2928, 2858.3, 2581 (SH), 1612, 1512, 1466, 1377, 1258, 1115, 1022, 895, 826 cm^{-1}; MS (70 eV): $m/z = 224$ ($M^+ + 2$, 1.2), 223 ($M^+ + 1$, 3.6), 222 (M^+, 20), 190 (18), 189 (100); HRMS: calcd. for $C_{14}H_{22}S$ (M^+): 222.1442, found: 222.1443.

*Preparation of 4-Trimethylsilylphenylmethanethiol (**5a**)* [18]

To a *THF* solution (100 cm^3) of 10 g of 4-bromotoluene (58 mmol) *n-Bu*Li (2.7 *M* *n*-hexane solution, 48 cm^3, 128 mmol) was added slowly at −78°C, and the resulting mixture was stirred for 40 min, then trimethylsilyl chloride (18 cm^3, 145 mmol) was added. The reaction was monitored by TLC to consume 4-bromotoluene. The reaction mixture was quenched with saturated-NH_4Cl solution, and extracted with *EtOAc*. The combined organic layer was washed with brine, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane) gave 8.9 g of *p*-tolyltrimethylsilane (93%). ^1H NMR ($CDCl_3$, 300 MHz): $\delta = 0.29$ [s, $Si(CH_3)_3$], 2.34 (s, $ArCH_3$), 7.19 (d, 2H, $J = 7.43$ Hz, ArH), 7.41 (d, 2H, $J = 7.98$ Hz, ArH); MS (70 eV): $m/z = 165$ ($M^+ + 1$, 2.2), 164 (M^+, 13), 150 (15), 149 (100), 121 (12); HRMS: calcd. for $C_{10}H_{16}Si$ (M^+): 164.1021, found: 164.1027.

A mixture of 400 mg of *p*-tolyltrimethylsilane (2.4 mmol), 434 mg of *N*-bromosuccinimide (2.4 mmol), and 3 mg of benzoyl peroxide (cat.) in 6 cm^3 of CCl_4 was refluxed for 2 h. The solvent was evaporated under reduced pressure. Purification of the residue by silica gel column chromatography (*n*-hexane) gave 440 mg of 4-trimethylsilylphenylmethyl bromide (75%). ^1H NMR (300 MHz, $CDCl_3$): $\delta = 7.51$ (d, $J = 8.2$ Hz, 2H), 7.37 (d, $J = 8.2$ Hz, 2H), 4.50 (s, 2H), 0.27 (s, 9H); IR ($CHCl_3$): $\bar{\nu} = 2959$, 2361, 1917, 1601, 1250 cm^{-1}; MS (70 eV): $m/z = 244$ ($M^+ + 2$, 3), 242 (M^+, 3), 229 (27), 227 (26), 163 (100), 148 (46), 148 (46), 135 (17), 110 (7), 105 (31), 91 (11); HRMS: calcd. for $C_{10}H_{15}BrSi$: 242.0126, found: 242.0128.

A mixture of 150 mg of 4-trimethylsilylphenylmethyl bromide (0.62 mmol) and 180 mg of thiourea (0.62 mmol) in 3 cm^3 of ethanol was refluxed for 14 h. After bubbling the reaction mixture with N_2 gas, 2 cm^3 of a 10% NaOH solution were added and the reaction mixture was refluxed for additional 3 h. The reaction mixture was neutralized with 1 *N* HCl, and extracted with ether. The ethereal layer was washed with H_2O, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane) gave 81 mg of **5a** (71%) [18]. ^1H NMR ($CDCl_3$, 300 MHz): $\delta = 0.27$ [s, $Si(CH_3)_3$], 1.76 (t, $J = 7.61$ Hz, SH), 3.74 (d, $J = 7.61$ Hz, CH_2S), 7.31 (d, 2H, $J = 7.98$ Hz, ArH), 7.49 (d, 2H, $J = 7.70$ Hz, ArH); MS (70 eV): $m/z = 196$ (M^+, 3), 165 (5), 164 (17), 163 (100), 149 (6), 148 (11), 135 (17).

*Preparation of 4-Trimethylsilylbenzenethiol (**9a**)* [19]

To a *THF* solution (2 cm^3) of 100 mg of 4-bromophenol (0.58 mmol) *n-Bu*Li (2.7 *M* *n*-hexane solution, 478 mm^3, 1.3 mmol) was added slowly at −78°C, and the resulting mixture was stirred for 40 min, then trimethylsilyl chloride (158 mm^3, 1.5 mmol) was added. The reaction was monitored by TLC to consume 4-bromophenol (4 h). The reaction mixture was quenched with 1 *N* HCl, and extracted with *Et*O*Ac*. The combined organic layer was washed with brine, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane/*Et*O*Ac* = 10/1) gave 75 mg of 4-trimethylsilylphenol (78%). ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 7.43$ (d, $J = 8.1$ Hz, 2H), 6.86 (d, $J = 8.1$ Hz, 2H), 4.76 (s, 1H), 0.27 (s, 9H); IR ($CHCl_3$): $\bar{\nu} = 3595$, 1597, 1504, 1246, 1107, 849 cm^{-1}; MS (20 eV): $m/z = 166$ (M^+, 9), 151 (25); HRMS: calcd. for $C_9H_{14}OSi$: 166.0814, found: 166.0800.

To a *DMF* solution (2 cm^3) of 75 mg of 4-trimethylsilylphenol (0.45 mmol) 22 mg of NaH (60%, 0.54 mmol) and 67 mg of dimethylthiocarbamoyl chloride (0.54 mmol) were added slowly at 0°C, and the resulting mixture was heated at 85°C for 6 h. The reaction mixture was neutralized with saturated-NH_4Cl solution and extracted with *Et*O*Ac*. The combined organic layer was washed with brine, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane/*Et*O*Ac* = 10/1) gave 114 mg of *O*-(4-trimethylsilylphenyl) dimethylthiocarbamate (100%). ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 7.54$ (d, $J = 9.3$ Hz, 2H), 7.06 (d, $J = 9.3$ Hz, 2H), 3.47 (s, 3H), 3.35 (s, 3H), 0.27 (s, 9H); IR ($CHCl_3$): $\bar{\nu} = 3020$, 1897, 1589, 1497, 1259, 1107, 1057 cm^{-1}; MS (70 eV): $m/z = 253$ (M^+, 7), 238 (3), 88 (57), 73 (9), 72 (100); HRMS: calcd. for $C_{12}H_{19}NOSiS$: 253.0957, found: 253.0955.

O-(4-Trimethylsilylphenyl) dimethylthiocarbamate (872 mg, 3.4 mmol) was heated at 240°C for 4 h in a glass oven. The crude product was purified by silica gel column chromatography (*n*-hexane/*Et*O*Ac* = 5/1) gave 718 mg of *S*-(4-trimethylsilylphenyl) dimethylthiocarbamate (82%). ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 7.53$ (d, $J = 8.7$ Hz, 2H), 7.46 (d, $J = 8.7$ Hz, 2H), 3.07 (s, 6H), 0.26 (s, 9H); IR ($CHCl_3$): $\bar{\nu} = 3020$, 1659, 1366, 1250, 1099 cm^{-1}; MS (70 eV): $m/z = 253$ (M^+, 8), 238 (4), 181 (2), 88 (4), 73 (5), 72 (100); HRMS: calcd. for $C_{12}H_{19}NOSiS$: 253.0957, found: 253.0966.

To a *THF* solution (30 cm^3) of 670 mg of *S*-(4-trimethylsilylphenyl) dimethylthiocarbamate (2.6 mmol) 310 mg of $LiAlH_4$ (7.9 mmol) were added portionwise at 0°C, and the resulting mixture was refluxed for 12 h. The reaction mixture was quenched with saturated-$MgSO_4$ solution and acidified with 1 *N* HCl, then extracted with *Et*O*Ac*. The combined organic layer was washed with brine, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane/*Et*O*Ac* = 25/1) gave 343 mg of **9a** (71%) [19]. Bp = 67–69°C; ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 7.44$ (d, $J = 6.0$ Hz, 2H), 7.25 (d, $J = 8.1$ Hz, 2H), 2.50 (s, 1H), 0.27 (s, 9H); IR ($CHCl_3$): $\bar{\nu} = 3059$, 1717, 1250, 1115 cm^{-1}; MS (70 eV): $m/z = 182$ (M^+, 27), 167 (100), 91 (8), 58 (43); HRMS: calcd. for $C_9H_{14}SiS$: 182.0586, found: 182.0575.

*Preparation of Dodecyl Methyl Sulfide (**12**)*

To a suspension of 751 mg of K_2CO_3 (5.43 mmol) in 3 cm^3 of *DMF* a *DMF* solution (2 cm^3) of 1 g of 1-dodecanethiol (**1**, 4.94 mmol) and 736 mg of MeI (5.19 mmol) was added at 0°C, and the resulting mixture was stirred at room temperature for 1 h. After the filtration of the reaction mixture, the filtrate was neutralized with 1 *N* HCl and concentrated *in vacuo*. The residue was added to H_2O, then extracted with *Et*O*Ac*. The organic layer was washed with sodium thiosulfate solution, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography gave 922 mg of **12** (86%). Colorless oil; bp = 110°C (0.2 mmHg); ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.49$ (t, $J = 7.4$ Hz, 2H), 2.10 (s, 3H), 1.59 (sextet, $J = 7.4$ Hz, 2H), 1.43–1.19 (m, 15H), 0.88 (t, $J = 6.9$ Hz, 3H).

*Typical Procedure for the New Odorless Swern Oxidation Using Dodecyl Methyl Sulfoxide (**13**)*

To a suspension of 95 mg of **13** (0.41 mmol) in 4 cm^3 of CH_2Cl_2 oxalyl chloride (1.0 *M* CH_2Cl_2 solution, 0.41 cm^3, 0.41 mmol) was added dropwise at −60°C, and the resulting mixture was stirred for

15 min. A CH_2Cl_2 solution (1 cm^3) of 50 mg of benzhydrol (0.27 mmol) was added dropwise at -60°C. The mixture was stirred for 30 min, 189 mm^3 triethylamine (1.36 mmol) were added dropwise, and the resulting mixture was gradually warmed to -40°C within 200 min. The reaction mixture was then warmed to room temperature by removing the cooling bath and stirred for 1 h. The mixture was quenched with 10 cm^3 of H_2O, and neutralized with 0.5 cm^3 of 1 *N* HCl, then extracted with $3 \times 40\,cm^3$ of $CHCl_3$. The combined organic layer was washed with brine, dried (Na_2SO_4), filtered, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography (*n*-hexane/*Et*O*Ac* = 40/1) gave 47 mg of benzophenone (95%) and 60 mg of **12** (100%).

A 10-times scale-up experiment under the above conditions using 500 mg of benzhydrol (2.7 mmol) gave 460 mg of benzophenone (93%), accompanied by 540 mg of **12** (92%).

*Typical Procedure for the New Odorless Corey-Kim Oxidation Using Dodecyl Methyl Sulfide (**12**)*

To 10 cm^3 of a CH_2Cl_2 or toluene solution of 108 mg of *N*-chlorosuccinimide (0.81 mmol) 2 cm^3 of a CH_2Cl_2 or toluene solution of 176 mg of **12** (0.81 mmol) were added dropwise at -40°C, and the resulting mixture was stirred for 30 min. A CH_2Cl_2 or toluene solution (2 cm^3) of 50 mg of benzhydrol (0.27 mmol) was added dropwise at -40°C. After the mixture was stirred for 2 h, 189 mm^3 of triethylamine (1.36 mmol) were added dropwise at -40°C. After stirring for 14 h, 20 cm^3 of H_2O were added to the reaction mixture. The mixture was neutralised with 0.5 cm^3 of 1 *N* HCl, followed by extraction of the aqueous layer with $3 \times 40\,cm^3$ of $CHCl_3$ or $3 \times 40\,cm^3$ of *Et*O*Ac*. The combined organic layer was washed with brine, dried (Na_2SO_4), filtered, and concentrated *in vacuo*. Silica gel chromatography of the residue (*n*-hexane/*Et*O*Ac* = 40/1) gave 47 mg of benzophenone (95% in CH_2Cl_2) or 49 mg (98% in toluene).

A 20-times scale-up experiment under the above conditions using 1.0 g of benzhydrol (5.43 mmol) gave 953 mg of benzophenone (96%).

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