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# A Practical Method for the Preparation of Trimethylsilyl Enol Ethers

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# A PRACTICAL METHOD FOR THE PREPARATION OF TRIMETHYLSILYL ENOL ETHERS

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Abstract: In the mixed system of chlorotrimethylsilane/triethyl amine/ N,N-dimethylformamide/potassium iodide/petroleum ether, aldehydes or ketones are silylated to silyl enol ethers at room temperature. The N,N-dimethylformamide / potassium iodie layer can be used as circulating liquor for many times. The yields are high.

Trimethylsilyl enol ethers have become extremely important intermediates in synthetic chemistry. <sup>1,2</sup> Their usefullness now surpasses that of all other enol derivatives. A number of methods have been developed for the preparation of trimethylsilyl enol ethers from aldehydes or ketones involving various reagents, such as, Me<sub>3</sub>SiCl / NaH or KH,<sup>3,4</sup> Me<sub>3</sub>SiCl / ZnCl<sub>2</sub>/ Et<sub>3</sub>N,<sup>5,6,7</sup> Me<sub>3</sub>SiCl/DMF/Et<sub>3</sub>N,<sup>8</sup> Me<sub>3</sub>SiCl/n-C<sub>4</sub>F<sub>9</sub>-SO<sub>3</sub>K/Et<sub>3</sub>N,<sup>9</sup> Me<sub>3</sub>SiI/NH (SiMe<sub>3</sub>)<sub>2</sub>,<sup>10</sup> Me<sub>3</sub>SiCl/NaI/Et<sub>3</sub>N/MeCN,<sup>11,12</sup> Me<sub>3</sub>SiCl / Li<sub>2</sub>S / Et<sub>3</sub>N,<sup>13</sup> Me<sub>3</sub>SiCl/EtN(i-C<sub>3</sub>H<sub>7</sub>)<sub>2</sub>,<sup>14</sup> Me<sub>3</sub>SiOSO<sub>2</sub>CF<sub>3</sub>/

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 $Et_3N$ , <sup>15</sup>  $CH_2 = CHCH_2SiMe_3/F_3CSO_3H/Et_3N$ , <sup>16</sup>  $Me_3SiOSO_2CH_3/$  $Et_{3}N$ ,<sup>17</sup> Me<sub>3</sub>SiN = C(CH<sub>3</sub>)OSiMe<sub>3</sub>,<sup>18</sup> Me<sub>3</sub>Si - SiMe<sub>3</sub>/Na,<sup>19</sup> Me<sub>3</sub>SiH / Co<sub>2</sub>(CO)<sub>8</sub>,<sup>20</sup> Me<sub>3</sub>SiCl / (Me<sub>2</sub>CH)<sub>2</sub>NLi / DME,<sup>21</sup> etc. From the above reported methods, Me<sub>3</sub>SiCl/ZnCl<sub>2</sub>/Et<sub>3</sub>N,<sup>5,6,7</sup>Me<sub>3</sub>SiCl / DMF / Et<sub>3</sub>N,<sup>8</sup> Me<sub>3</sub>SiCl / NaI / MeCN,<sup>11,12</sup> and Me<sub>3</sub>SiCl /Li<sub>2</sub>S / Et<sub>3</sub>N,<sup>13</sup> are convenient and inexpensive procedures in which the silvlating and other reagents do not need special preparation. However the yield of silyl enol ethers obtained by these methods for some aldehydes or ketones is not always satisfactory. Three factors lower the yield: (1) In the case of polar solvents, such as DMF,<sup>8</sup> MeCN / NaI,<sup>11,12</sup> the solvent was removed by water washings and a small part of products are lost in water. (2)When hydrolysis is necessary a part of silvl enol ethers is changed to aldehydes or ketones.<sup>22</sup> ③ In many cases, the boiling point of silvl enol ethers differs little from corresponding aldehydes or ketones,  $\rightarrow$  OSiMe<sub>3</sub>,76°C/30,  $\langle$  $\rightarrow 0$ , 67.8°C/40; such as  $C_{6}H_{5}(Me_{3}SiO)C = CH_{2}, 79^{\circ}C/10, C_{6}H_{5}COCH_{3} 82^{\circ}C/5; C_{5}H_{11}CH_{2}CHO^{\circ}CH_{2}$ 59. 6°C/30, C<sub>5</sub>H<sub>11</sub>CH=CHOSiMe<sub>3</sub> 83°C/25. So, a part of the products are collected together with the aldehydes or ketones by fractional distillation. These led us to utilize the surprising simple, convenient, inexpensive and high-yield method of DMF/KI as circulating system, i.e. Me<sub>3</sub>SiCl/DMF/KI/petroleum ether/Et<sub>3</sub>N method;

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Iodotrimethylsilane is more reactive than chlorotrimethylsilane,  $^{10,23}$  but its applicability is limited because it must be prepared in two steps from chlorotrimethylsilane.  $^{24,25}$  We assumed it might be possible to use iodotrimethylsilane prepared in situ:

$$Me_{3}SiCl + KI \xrightarrow{DMF} Me_{3}SiI + KCl$$
Scheme 2

In order to overcome the above three factors effects in yield, we used DMF / KI as circulating mother liquor system. In every sequence, only the petroleum ether layer was hydrolyzed and fractional distilled. The early fractions, which contain aldehyde or ketone and a small part of trimethyl silyl enol ether were added to the next experimental procedure. The solid ( $Et_3NHC1$ ) was first washed with a small amount of DMF and then extracted with petroleum ether. The reaction time of 10 h at room temperature was chosen.

The circulating mother liquor can be used many times. Six times was chosen in our experiments. The loss of DMF is minor, and so, the method inexpensive. Every experimental procedure is very simple. Stirring and specially dried equipment are not necessary. The yield (86%-98%, Table 1) is higher than by other methods reported. The regiose-lectivity obtained for structural isomers, except steric unsymmetrical ketone le, can be reasoned assuming thermodynamic controlled products. The double bond stereoselectivity is Z isomer in the case of enoxysilanes 2c-E, 2c-Z, 2e-E, 2e-Z, 2g-E, 2g-Z, and E isomer in the case of dienoxysilanes 2h-E, 2h-Z, 2i-E.

The results and physicochemical data are listed in Table 1.

Aldehyde or Ketone	Silyl enol ether	Average yield, %; bp [lit. bp] ('C/mmHg)(isomer, %)
◯—0 la	OSiMe <sub>3</sub> 2a	96; 76-78/30 [76/30] <sup>12</sup>
C₅H₅COCH₃ lb	$OSiMe_3$ $C_6H_5C = CH_2$ $2b$	98; 92-94/15 [82/5] <sup>12a</sup>
CH₃CH₂COCH₃ lc	$CH_{3}CH_{2}C = CH_{2}$ $CH_{3}CH_{2}C = CH_{2}$ $CH_{3}$ $C = C$ $CH_{3}$ $CH_{3}$ $CH_{3}$ $CH_{3}$ $CH_{3}$ $C = C$ $CH_{3}$ $CH_{3}$ $C = C$ $CH_{3}$	95; 108-118/760 (25)[120/760] <sup>12</sup> (E,5) (Z,70)
CH <sub>3</sub> Id	$OSiMe_3 \qquad 2d$ $CH_3$ $OSiMe_3 \qquad 2d''$ $CH_3$	97; 85-93/32 (18)[90/20] <sup>12</sup> * (82)
(CH₃)₂CHCH₂COCH₃ le	$(CH_3)_2CHCH_2C = CH_2$ $2e^{-}$ $(CH_3)_2CH$ $C = C$ $H$ $OSiMe_3$ $(CH_3)_2CH$ $C = C$ $CH_3$ $2e-E$ $CH_3$ $2e-Z$ $C = C$ $2e-Z$ $CH_3$	94; 50-60/38 (58)[86/105] <sup>1</sup> <sup>2</sup> (E,8.7) (Z,33.3)

# Table 1 Results and Physicochemical Data of Trimethylsilyl enol ethers from Aldehydes or Ketones

	Table 1 continued	
(CH₃)₂CHCHO lf	$(CH_3)_2C = CHOSiMe_3$ 2f	93; 118-119/760 [69/120] <sup>12a</sup>
C₄H₅CH2CH2CH0 1g	$C_{4}H_{9}CH_{2} \qquad H$ $C = C \qquad 2g-E$ $H \qquad OSiMe_{3}$ $C_{4}H_{9}CH_{2} \qquad OSiMe_{3}$	95; 98-102/48 [83/25] <sup>12a</sup> (E, 33.3)
	C = C $2g-ZH H$	( <b>Z</b> , 66.7)
(CH₃)₂C=CHCOCH₃ lh	$(CH_3)_2C = \begin{array}{c}H & OSiMe_3\\  &  \\CH_2\\C \rightarrow C = CH_2\\2h\\H & OSiMe_3\end{array}$	92; 74-77/37 (91)[65/30] <sup>126</sup>
	$H_{2}C = C - C = C - CH_{3} - 2h - E$ $CH_{3} = OSiMe_{3}$	(E,5.5)
	$H_2C = C - C = C - CH_3  2h-Z$ $  \qquad   \qquad CH_3H$	(Z,3.5)
CH₃CH=CHCHO li	$H_{e} = CH_{e} - C_{e} = H_{a}$ $H_{d} = H_{b}$ $H_{b} = C-OSiMe_{3}$ $H_{c} = C-OSiMe_{3}$ $H_{c} = C + C_{c} = C + C_{c}$	86; 133-136/760 [56/60] <sup>12b</sup> (E, 100%)

## **Experimental Section**

Infrared spectra were obtained with IR-408 spectrometer. Proton nuclear resonance spectra were recorded at 90 MHz on JEOL-FX 90Q spectrometer using CDCl<sub>3</sub> as solvent and residual CHCl<sub>3</sub> in CDCl<sub>3</sub> as internal standard. Analytically pure aldehydes and ketones were distilled

before use and stored over molecular sieves 3A. Triethyl amine and DMF were dried over potassium carbonate and distilled (for triethyl amine)or distilled in vacuum (for DMF). Analytically pure petroleum ether (30-60°C) was shaken 3-5 times with sulfuric acid until the sulfuric acid layer appeared colourless, then washed with water, dried over calcium chloride, distilled and stored over sodium wire. KI was dried 12h at 150°C and stored under nitrogen.  $\geq$ 99.5% purity chlorotrime-thylsilane was used.

## Typical Procedure for 1-Trimethylsiloxy cyclohexene (2a):

The first experimental procedure: At room temperature, to a solution of potassium iodide (6. 64 g, 0. 04 mol) in N, N-dimethylformamide (40 mL), petroleum ether (30-60°C, 15 mL), triethyl amine (12.1g, 0.12 mol), cyclohexanone (9.8g, 0.1 mol), was added 11. 4 g(0. 105 mol)of chlorotrimethylsilane via syringe. The flask was sealed immediately by capping plug. Shake the mixture for 5 minutes and then keep at room temperature for 10 h. Separate the petroleum ether layer from the DMF / KI layer. The solid Et<sub>3</sub>NHCl in DMF layer was filtered in vacuum and washed with 5 mL DMF. The filter liquor was mixed with the DMF/KI layer as next circulating mother liquor. The solid was extracted with petroleum ether ( $2 \times 50$  mL). The petroleum ether extract was combined with above petroleum ether layer and washed rapidly with cold saturated sodium chloride  $(2 \times 10 \text{ mL})$ . The resulting petroleum ether solution was dried over magnesium sulfate and distilled at atmospheric pressure to collect petroleum ether and then in vacuum through a Vigreux column. The head cut ( $\leq 76$ °C/30 mmHg) was collected in a single flask for next the experiment procedure. 11.9 g of product (b. p  $76-78^{\circ}C/30$ mm Hg) was obtained.

Second to fifth experimental procedure: To the DMF/KI circulating mother liquor from above, petroleum ether (15 mL), head cut ( $\leq$  76°C/30 mmHg) of previous experimental procedure, triethyl amine (11. 1 g, 0. 11 mol), cyclohexanone (9. 8 g, 0. 1 mol) and chlorotrimethylsilane (11. 4 g, 0. 105 mol) were added. The reaction flask was sealed by capping plaug. The mixture was shaken for 5 minutes and then rested for 10 h at room temperature. After treatment according to the first experimental procedure, 14. 1 g, 15. 7 g, 16. 1 g, 17 g product were obtained from second to fifth experimental procedure.

Sixth experimental procedure: As described for the second to fifth experimental procedure, let the reactants react for 10 h at room temperature. Separate the petroleum ether layer from the DMF/KI layer. The solid was filtered and extracted with petroleum ether  $(2 \times 50 \text{ mL})$ . The DMF/KI layer was extracted with petroleum ether  $(2 \times 150 \text{ mL})$ . The combined petroleum ether layers were washed rapidly with cold saturated sodium chloride  $(3 \times 15 \text{ mL})$  and dried over magnesium sulfate. 23.3 g of product was obtained by distillation in vacuum.

98.1 g of product was obtained in total of the six experiments. The average yield is 96%.

2a.  $v_{max}/cm^{-1}$  1668;  $\delta 4.73$  (t. br. 1H, H-C=), 1.94 (m. br. 4H), 1.74 (m, br. 4H), 0.52 (s, 9H, Me<sub>3</sub>Si)

2b.  $v_{max}/cm^{-1}$  1620;  $\delta$ 7. 46 (m,2H,Ph), 7.2 (m,3H,Ph), 4.80 (d,<sup>2</sup>J = 2,1H) and 4.32 (d,<sup>2</sup>J=2,1H) (H<sub>2</sub>C=), 0.22 (s,9H,Me<sub>3</sub>Si)

2c. 
$$v_{max}/cm^{-1}$$
 1635; 54. 18 and 4. 08 (s,  $H_2C=$ ), 2. 04 (q,  ${}^{3}J=7.5$ , CH<sub>2</sub>), 1. 00 (t,  ${}^{3}J=7.5$ , CH<sub>3</sub>), 0. 16 (s, Me<sub>3</sub>Si)  
2c-E.  $v_{max}/cm^{-1}$  1680; 54. 76 (q,  ${}^{3}J=6.8$ , HC=), 1. 72 (S, CH<sub>3</sub>-C-OSi), 1. 47 (d,  ${}^{3}J=6.8$  CH<sub>3</sub>-C=), 0. 22 (S, Me<sub>3</sub>Si)  
2c-Z.  $v_{max}/cm^{-1}$  1680; 54. 46 (q,  ${}^{3}J=6.8$ , HC=), 1. 79(S, CH<sub>3</sub>COSi),  
1. 49 (d,  ${}^{3}J=6.8$ , CH<sub>3</sub>C=), 0. 22(S, Me<sub>3</sub>Si)  
2d´.  $v_{max}/cm^{-1}$  1660; 54. 74 (t,  ${}^{3}J=3.7$ , HC=), 1. 92–1. 50 [m,  
(CH<sub>2</sub>)<sub>3</sub>], 0. 98(d,  ${}^{3}J=6.5$ , CH<sub>3</sub>), 0. 12(S, Me<sub>3</sub>Si).  
2d″.  $v_{max}/cm^{-1}$  1686; 51. 92–1. 50 [m, (CH<sub>2</sub>)<sub>4</sub>], 1. 54 (S, CH<sub>3</sub>C=),  
0. 12(S, Me<sub>3</sub>Si)  
2e´.  $v_{max}/cm^{-1}$  1685, 1635, 1618; 54. 02 and 3. 98 (S, H<sub>2</sub>C=), 1. 85  
(d. br. CH<sub>2</sub>), 0. 98–0. 85 (m, (CH<sub>3</sub>)<sub>2</sub>CH), 0. 18 (S, Me<sub>3</sub>Si)  
2e´.  $v_{max}/cm^{-1}$  1680; 54. 48 (d,  ${}^{3}J=9.3$ , HC=), 1. 88 [m, H-C-  
(C)<sub>2</sub>], 1. 72 (S, CH<sub>3</sub>-COSi), 0. 98–0. 85 (d, (CH<sub>3</sub>)<sub>2</sub>C), 0. 2 (S,  
Me<sub>3</sub>Si)  
2e-Z.  $v_{max}/cm^{-1}$  1680; 54. 26 (d,  ${}^{3}J=9.3$ , HC=), 1. 88 [m, H-C-  
(C)<sub>2</sub>], 1. 72 (S, CH<sub>3</sub>COSi), 0. 98–0. 85 (d, (CH<sub>3</sub>)<sub>2</sub>C), 0. 2 (S,  
Me<sub>3</sub>Si)  
2f.  $v_{max}/cm^{-1}$  1685; 55. 98 (m, HC=), 1. 58(d, 4J=1.6, CH<sub>3</sub>), 1. 52  
(d,  ${}^{4}J=1.6, CH_{3}$ ), 0. 12(S, Me<sub>3</sub>Si)  
2g-E.  $v_{max}/cm^{-1}$  1655; 66. 16 (d,  ${}^{3}J=12$ , H-COSi), 4. 96 (m,  ${}^{3}J=12$ ,  
H-C=C-H;  ${}^{3}J=7$ , H-C-C-H; H-C-C), 2. 02 (m, CH<sub>2</sub>), 1. 3 [m,  
(CH<sub>2</sub>)<sub>3</sub>], 0. 88 (t, br. CH<sub>3</sub>), 0. 16(S, Me<sub>3</sub>Si)

 $2g-Z. \nu_{max}/cm^{-1} 1655; \delta 6. 12 (d, {}^{3}J=6, H-C-OSi), 4. 46 (q, {}^{3}J=6, H-C-C), 2. 02(m, CH_{2}), 1. 3 (m, (CH_{2})_{3}), 0. 88 (t, br. CH_{3}), 0. 16(S, Me_{3}Si)$ 

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2h.  $v_{max}/cm^{-1} 1655(Vc=cosi)$ , 1630(Vc=c);  $\delta 5.51$  (S, br. H-C-C =), 4. 21 and 4. 12 (S, H<sub>2</sub>C=), 1. 87 and 1. 74 (S, br. CH<sub>3</sub>), 0. 18 (S, Me<sub>3</sub>Si) 2h-E.  $v_{max}/cm^{-1} 1655(Vc=cosi)$ , 1630(Vc=c);  $\delta 4.94$  (S, HC =), 4. 86 and 4. 62(S, br. H<sub>2</sub>C=), 1. 87 (s. br. CH<sub>3</sub>-C-C), 1. 41 (d. CH<sub>3</sub>-C-OSi), 0. 14 (S, Me<sub>3</sub>Si) 2h-Z.  $v_{max}/cm^{-1} 1655(Vc=cosi)$ , 1630(Vc=c);  $\delta 4.82$  (S, HC =), 4. 86 and 4. 62(S, br. H<sub>2</sub>C=), 1. 87 (d. br. CH<sub>3</sub>-C-C), 1. 41 (d. CH<sub>3</sub>-C-OSi), 0. 14 (S, Me<sub>3</sub>Si) 2h-Z.  $v_{max}/cm^{-1} 1645(Vc=cosi)$ , 1600(Vc=c);  $\delta 6.39$  (d, <sup>3</sup>J=11, Ha), 5. 52(d, <sup>3</sup>J=11, H<sub>b</sub>), 6. 05 (m, Hc), 4. 84 (m, H<sub>d</sub>) 4. 68 (m, H<sub>e</sub>) 0. 08 (S, Me<sub>3</sub>Si)

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