CHE78-02081) for funds used to purchase an NMR spectrometer.

Registry No. **1a**, 13952-67-5; **1b**, 6281-65-8; **1c**, 42399-75-7; **1d**, 50780-07-9; **1e**, 76613-17-7; **1f**, 76613-18-8; **1g**, 39198-31-7; **1h**, 76613-19-9; **1i**, 76613-20-2; **1j**, 76613-21-3; **1k**, 61455-16-1; **2a**, 40121-14-0; **2b**, 50780-12-6; **2c**, 42399-76-8; **2d**, 50780-13-7; **2e**, 76613-22-4; **2f**, 76613-23-5; **2g**, 76613-24-6; **2h**, 76613-25-7; **2i**, 76613-26-8; **2j**, 76613-27-9; **2k**, 76613-28-0; **3b**·H_2SO_4, 76613-30-4; **4b**, 39198-34-0; **9a**, 42028-71-7; **9b**, 76613-31-5; **9c**, 76613-32-6; **13**, 1189-71-5; **15a**, 75-65-0; **15f**, 617-94-7; **15g**, 594-83-2; **15h**, 2370-12-9; **15i**, 14202-62-1; **15j**, 100-86-7; **15k**, 5340-85-2; **16g**, 39198-35-1; **16j**, 5531-33-9; **16k**, 76613-33-7; **17f**, 32366-26-0; **17h**, 76613-34-8; **17i**, 76613-35-9; **18a**, 75-64-9; **18b**, 107-45-9; **18c**, 768-94-5; **18f**, 585-32-0; **18g**, 29772-54-1; **18h**, 2626-64-4; **18i**, 76613-36-0; **18j**, 122-09-8; **18j**·HCl, 1197-21-3; **18k**, 61455-15-0; **23**, 76613-37-1; **24**, 76613-38-2.

Interconversion of γ-Silyl α,β-Unsaturated Carbonyl Compounds and Siloxybutadienes by 1,5-Shifts of Silicon between Carbon and Oxygen

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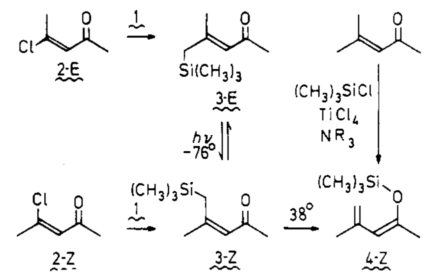
Reaction of lithium bis[(trimethylsilyl)methyl]cuprate (1) with (*E*)-4-chloro-3-penten-2-one (**2-E**) gives (*E*)-4-methyl-5-(trimethylsilyl)-3-penten-2-one (**3-E**). Photolysis of **3-E** at low temperature gives a 56:44 mixture of **3-E** and **3-Z**. Upon being warmed to 34 °C, **3-Z** undergoes a migration of silicon from carbon to oxygen to produce 2-methyl-4-(trimethylsiloxy)-2,4-pentadiene (**4-Z**). The reaction of 1 with methyl (*E*)-3-chloro-2-butenoate (**5-E**) leads to the formation of methyl (*E*)-3-methyl-4-(trimethylsilyl)-2-butenoate (**6-E**). Photolysis of **6-E** leads to a mixture of **6-E** and **6-Z**. Both **6-E** and **6-Z** are thermally stable and do not undergo silicon migration from carbon to oxygen for thermodynamic reasons. In fact, 1-methoxy-1-(trimethylsiloxy)-3-methyl-1,3-butadiene (**7**) undergoes a silicon migration from oxygen to carbon to give **6-Z**.

Several years ago we reported that β-acetoxy α,β-unsaturated carbonyl compounds react with lithium dialkylcuprate reagents to give γ-alkyl α,β-unsaturated carbonyl compounds.[1] Similar substitutions of alkyl groups for β-Cl, β-SR, and β-$OPO(OR)_2$ are known.[2] We decided to study the reactions of β-chloro α,β-unsaturated carbonyl compounds with $[(CH_3)_3SiCH_2]_2CuLi$ (**1**) in an attempt to generate γ-trimethylsilyl α,β-unsaturated carbonyl compounds. These compounds are of potential synthetic interest in light of the rich chemistry of allylsilanes.[3] In addition, the products are attractive precursors for the stereoselective generation of trimethylsiloxy-substituted butadienes via a 1,5-shift of silicon from carbon to oxygen. The use of oxygen-substituted dienes in Diels–Alder reactions has been shown to be of great synthetic utility by Danishefsky.[4]

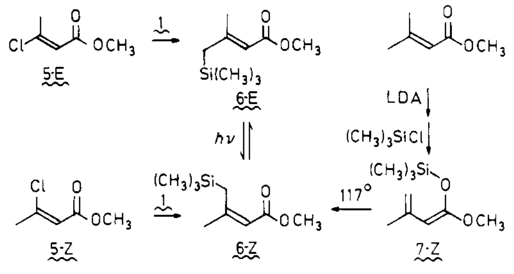
Results

Ketones. Although the synthesis of lithium bis[(trimethylsilyl)methyl]cuprate (1) had been previously reported by Lappert and by Brown,[5] its use as a reagent has not been mentioned. Solutions of $[(CH_3)_3SiCH_2]_2CuLi$ are stable at room temperature and are easily prepared by addition of 2 equiv of $(CH_3)_3SiCH_2Li$ to a suspension of CuI in ether or THF.

Scheme I



Scheme II



Reaction of 1 with (*E*)-4-chloro-3-penten-2-one[6] (**2-E**) proceeded rapidly at −15 °C to give (*E*)-4-methyl-5-(trimethylsilyl)-3-penten-2-one (**3-E**, Scheme I) in 51% isolated yield. Examination of the reaction mixture by gas chromatography showed a 74% yield of **3-E**. The stereochemistries of ketones **3-E** and **3-Z** are readily assigned on the basis of the deshielding of substituents cis to the carbonyl group. The allylic methyl group of **3-E** is cis to the ketone and is shifted downfield (δ 2.11) relative to the trans allylic group of **3-Z** (δ 1.65). Similarly, the cis CH_2Si

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(4) Danishefsky, S.; Kitahara, T.; Yan, C. F.; Morris, J. *J. Am. Chem. Soc.* **1979**, *101*, 6996 and references therein.

(5) Lappert, M. F.; Pearce, R. *J. Chem. Soc., Chem. Commun.* **1973**, 24. Kieft, R. L.; Brown, T. L. *J. Organomet. Chem.* **1974**, *77*, 289. Jarvis, J. A. J.; Pearce, R.; Lappert, M. F. *J. Chem. Soc., Dalton Trans.* **1977**, 999.

(6) Clark, R. D.; Heathcock, C. H. *J. Org. Chem.* **1976**, *41*, 636.

0022-3263/81/1946-2089$01.25/0

group of **3-Z** (δ 2.50) appears downfield of the trans CH_2Si group of **3-E** (δ 1.34).

The reaction of cuprate **1** with (*Z*)-4-chloro-3-penten-2-one (**2-Z**) was less straightforward. Small, nearly equal amounts of **3-E** and **3-Z** were formed together with a larger amount of **4-Z**, which presumably arises from **3-Z** via a 1,5-shift of the trimethylsilyl group.

The photoisomerization of **3-E** was studied at low temperatures in an effort to directly observe **3-Z**. When a toluene-d_8 solution of **3-E** was photolyzed at −76 °C, a photostationary state consisting of a 56:44 mixture of **3-E**/**3-Z** was formed within 1 h. When this mixture of **3-E**/**3-Z** was warmed to 34 °C, the conversion of **3-Z** to a single isomer of 2-methyl-4-(trimethylsiloxy)-2,4-pentadiene (**4**) occurred with a half-life of 77 min ($k = 1.5 \times 10^{-4}$ s^{-1}, $\Delta G^{\ddagger} = 23$ kcal mol^{-1}). Since the 1,5 silicon migration from carbon to oxygen occurs only from isomer **3-Z** in which the ketone and (trimethylsilyl)methyl group are cis, it is reasonable to assume that diene **4** has the *Z* configuration.

The structure of diene **4-Z** was assigned on the basis of IR and NMR spectra (see Experimental Section) and independent synthesis. Reaction of 4-methyl-3-penten-2-one with $(CH_3)_3SiCl$ in the presence of $TiCl_4$ and $N(CH_2CH_3)_3$ gave a 1.2:1 mixture of **4-Z** and 4-methyl-2-(trimethylsiloxy)-1,3-pentadiene.

Esters. Reaction of methyl (*E*)-3-chloro-2-butenoate (**5-E**) with cuprate **1** proceeded smoothly to give methyl (*E*)-3-methyl-4-(trimethylsilyl)-2-butenoate (**6-E**, Scheme II) in 80% yield along with 10% of isomer **6-Z**. In contrast, reaction of cuprate **1** with **5-Z** was inefficient and nonstereospecific. Even after treatment with **1** for 16 h at room temperature, 45% unreacted **5-Z** could be recovered. The substitution products were shown to be a 1:2.3 mixture of **6-Z** and **6-E**. The configurations of **6-Z** and **6-E** were assigned on the basis of their NMR spectra. The *C*-methyl group of **6-E** is cis to the carbonyl group and is deshielded (δ 2.22) relative to the trans *C*-methyl group of **6-Z** (δ 1.52). The cis CH_2Si group of **6-Z** is similarly deshielded (δ 2.46) relative to the trans CH_2Si group of **6-E** (δ 1.41).

As in the case of the ketones, the esters were photoequilibrated. Irradiation of a pentane solution of **6-E** led to a photostationary state consisting of a 1.7:1.0 mixture of **6-E**/**6-Z**.

Both silyl esters **6-E** and **6-Z** were surprisingly thermally stable. No decomposition was noted even upon prolonged heating at 140 °C. To determine why neither **6-E** nor **6-Z** underwent silicon migration from carbon to oxygen, we prepared the expected vinyl ketene acetal. Methyl 3-methyl-2-butenoate was deprotonated with lithium diisopropylamide at 0 °C. The resulting enolate was reacted with $(CH_3)_3SiCl$ at 0 °C to give a 1:1 mixture of (*Z*)- and (*E*)-1-methoxy-1-(trimethylsiloxy)-3-methyl-1,3-butadienes (**7-Z** and **7-E**). Distillation at 65 °C (1 mm) led to isomerization of the mixture of vinyl ketene acetals to a single isomer of **7**, whose structure was not assigned.

Thermolysis of ketene acetal **7** at 117 °C led to the formation of a 1:1 mixture of **6-Z** and of $(CH_3)_3SiOCH_3$. The decomposition of **7** followed clean first-order kinetics and had a 2-h half-life at 117 °C ($k = 9.6 \times 10^{-5}$ s^{-1}, $\Delta G^{\ddagger} = 30$ kcal mol^{-1}).

Discussion

Cuprate Reactions. The reactions of both **2-E** and **5-E** with lithium bis[(trimethylsilyl)methyl]cuprate (**1**) lead to substitution products with predominant retention of stereochemistry and provide efficient routes to the allylic silanes **3-E** and **6-E**. In contrast, the reactions of the corresponding *Z* isomers with **1** are slow and nonstereospecific and proceed in low yield. Earlier we had observed a similar problem in the reaction of methyl (*Z*)-3-acetoxy-2-butenoate with $LiCu(CH_2CH_3)_2$ which gave 19% yield of reduction product, methyl (*E*)-2-butenoate, in addition to the normal substitution products.[1] The reduction product was suggested to arise via displacement of acetoxy by copper followed by hydrolysis of the resulting copper compound. Even greater discrepancies between the reaction of *Z* and *E* isomers were seen in the reactions of β-chloro esters **5-E** and **5-Z** with diethylcuprate.[7] Reaction of **5-E** with diethylcuprate gave a 97% yield of the substitution product methyl (*E*)-3-methyl-2-pentenoate and only 1% of the reduction product methyl 2-butenoate; in contrast, reaction of **5-Z** with diethylcuprate gave a 24% yield of a 3:1 ratio of methyl (*Z*)- and (*E*)-3-methyl-2-pentenoates and a 67% yield of the reduction product methyl 2-butenoate.

1,5 Silicon Migrations. It is interesting that γ-silyl ketone **3-Z** undergoes a migration of silicon from carbon to oxygen to give siloxy diene **4-Z** while γ-silyl ester **6-Z** is formed by migration of silicon from oxygen to carbon upon thermolysis of vinylketene acetal **7-Z**. This contrasting behavior is entirely due to thermodynamics. In any migration of silicon from carbon to a carbonyl oxygen there are two effects working in opposition. The greater strength of Si–O bonds (~112 kcal) relative to Si–C bonds (~73 kcal) favors migration from carbon to oxygen;[8] however, the greater strength of C═O double bonds relative to C═C double bonds favors migration from oxygen to carbon. For ketone **3-Z**, the preference for silicon bonded to oxygen dominates, and complete rearrangement of **3-Z** to siloxy diene **4-Z** is observed. For ester **5-Z**, the greater stability of the resonance-stabilized C═O bonds of esters compared with the C═O bonds of ketones tips the energy balance in favor of the silicon–carbon-bonded isomer **6-Z** over **7-Z**.[9] For nonconjugated species, similar results have been observed: $CH_3C(O)CH_2Si(CH_3)_3$ rearranges to $(CH_3)[(CH_3)_3SiO]C{=}CH_2$,[11] but $CH_2{=}C[OSi(CH_3)_3](OCH_3)$ rearranges to $(CH_3)_3SiCH_2CO_2CH_3$,[12] and $CH_2{=}C[OSi(CH_3)_3]N(CH_3)_2$ rearranges to $(CH_3)_3SiCH_2CON(CH_3)_2$.[13]

The rate of 1,5-shift of silicon from carbon to oxygen in the rearrangement of ketone **3-Z** to siloxy diene **4-Z** is rapid ($k = 1.5 \times 10^{-4}$ s^{-1} at 34 °C, $\Delta G^{\ddagger} = 23$ kcal) compared with the reported rates of 1,3-shifts of silicon from carbon

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(7) Marten, D. F., Ph.D. Thesis, University of Wisconsin, 1974.

(8) For approximate thermochemical bond energies for silicon see: Wright, A.; West, R. *J. Am. Chem. Soc.* **1974**, *96*, 3214 and references therein.

(9) By use of Benson's[10] group equivalents and reasonable extrapolations for handling enol ethers and ketene acetals, heats of formation were calculated as follows: $CH_2{=}C(CH_3)CH{=}C(OCH_3)CH_3$, −29 kcal; $(CH_3CH_2)(CH_3)C{=}CHCOCH_3$, −48 kcal; $CH_2{=}C(CH_3)CH{=}C(OCH_3)_2$, −62 kcal; $(CH_3CH_2)(CH_3)C{=}CHCOOCH_3$, −92 kcal. Thus the approximate ΔH for carbon migration from carbon to oxygen for an unsaturated ketone would be 19 kcal mol^{-1} and for an unsaturated ester −30 kcal mol^{-1}. For similar silicon migrations from carbon to oxygen, both values would be increased by large amounts due to the differences in bond energies for C–C (83 kcal) and C–O (86 kcal) relative to Si–C (73 kcal) and Si–O (112 kcal). It is therefore reasonable that the silicon–oxygen-bonded isomer is more stable for ketones while the silicon–carbon-bonded isomer is more stable for esters.

(10) Benson, S. W.; Cruickshank, F. R.; Golden, D. M.; Haugen, G. R.; O'Neal, H. E.; Rodgers, A. S.; Shaw, R.; Walsh, R. *Chem. Rev.* **1969**, *69*, 279.

(11) Brook, A. G. *Acc. Chem. Res.* **1974**, *7*, 77. Brook, A. G.; MacRae, D. M.; Limburg, W. W. *J. Am. Chem. Soc.* **1967**, *89*, 5493. Litvinova, O. V.; Baukov, Y. I.; Lutsenko, I. F. *Dokl. Akad. Nauk USSR* **1967**, *173*, 578.

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(13) Lutsenko, I. F.; Baukov, Y. I.; Kostyuk, A. S.; Savelyeva, N. I.; Krysina, V. K. *J. Organomet. Chem.* **1969**, *17*, 241. See also: Woodbury, R. P.; Rathke, M. W. *J. Org. Chem.* **1978**, *43*, 881.

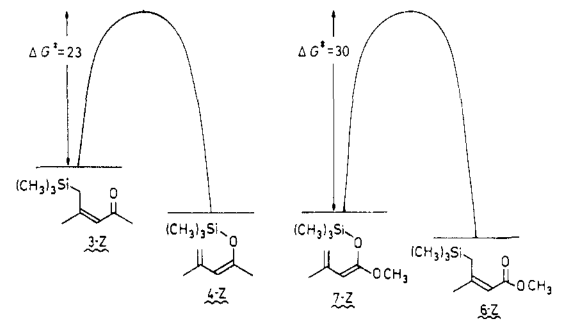

Figure 1. Free-energy diagram for 1,5-silicon shifts from carbon to oxygen.

to oxygen (E_a = 30 kcal) in the rearrangement of β-ketosilanes to enol silyl ethers.[11] This is in accord with observations that 1,5 silicon shifts are more rapid than 1,3-shifts. For example, the orbital symmetry allowed, 1,5 sigmatropic shift of silicon in 5-(trimethylsilyl)cyclopentadiene is a very facile process ($\Delta G^\ddagger$ = 15 kcal),[14] but the 1,3 sigmatropic shift of silicon from carbon to carbon in allylsilanes is slow (E_a = 48 kcal) and occurs with inversion of stereochemistry at the migrating silicon atom as predicted by orbital symmetry arguments.[15] The 1,3-shift of silicon from carbon to oxygen in β-ketosilanes is slow (E_a = 30 kcal) but proceeds with retention of stereochemistry at silicon; the reaction has been proposed to proceed via a zwitterionic, five-coordinate, silicon intermediate.[11,16] The relatively rapid rearrangement of **3-Z** to **4-Z** is best understood as an orbital symmetry allowed, 1,5 sigmatropic rearrangement.

The migration of silicon from oxygen to carbon which occurs in the rearrangement of siloxy diene **7-Z** to ester **6-Z** is slower ($k = 10^{-4}$ s^{-1} at 117 °C, $\Delta G^\ddagger$ = 30 kcal) than the rearrangement of ketone **3-Z** to siloxy diene **4-Z**. This rate difference can be understood in terms of the energy profile shown in Figure 1. Neither the siloxy dienes **4-Z** and **7-Z** nor the transition states for rearrangement should have their energies greatly affected by substitution of OCH_3 for CH_3 on the siloxy-substituted vinylic carbon atom. However, substitution of OCH_3 for CH_3 in the α,β-unsaturated carbonyl compounds **3-Z** and **6-Z** would differentially stabilize the ester **6-Z** by a resonance interaction. This explains not only the different directions of the equilibria between **3-Z** ⇄ **4-Z** and **6-Z** ⇄ **7-Z** but also the more rapid isomerization of **3-Z** → **4-Z** compared with the isomerization of **7-Z** → **6-Z**.

Experimental Section

General Methods. Diethyl ether (Et_2O) and tetrahydrofuran (THF) were distilled from sodium benzophenone ketyl. All reactions involving organolithium or organocopper reagents were carried out under an atmosphere of dry nitrogen in flame-dried glassware.

Analytical gas chromatography was carried out on a Hewlett-Packard 5700A instrument with a flame ionization detector coupled with a Hewlett-Packard 3380A electronic integrator. Preparative gas chromatographic separations were carried out on a Varian 90P instrument. Preparative thin-layer chromatography was done by using Merck PF-254 silica gel.

NMR spectra were recorded on JEOL MH-100, FX-60, and FX-200 and on Bruker WH-270 spectrometers. All chemical shifts are reported in parts per million (δ) relative to internal $(CH_3)_4Si$. Infrared spectra were recorded on a Perkin-Elmer 267 grating infrared spectrophotometer or on a Digilab FTS-20 Fourier transform spectrophotometer. Mass spectra were recorded on an AE-1-MS902 spectrometer at 70 eV.

(*E*)-4-Chloro-3-penten-2-one was synthesized as described by Heathcock[6] and was isolated by GC (10% Carbowax 20M, 105 °C; coinjection with $HN[Si(CH_3)_3]_2$ prevented isomerization on the column).

$(CH_3)_3SiCH_2Li$ was prepared from $(CH_3)_3SiCH_2Cl$ and lithium in pentane as described.[17]

(*E*)-4-Methyl-5-(trimethylsilyl)-3-penten-2-one (3-E). A solution of $[(CH_3)_3SiCH_2]_2CuLi$[5] (1), prepared by adding $(CH_3)_3SiCH_2Li$ (190 mg, 2.00 mmol) in 5 mL THF to a stirred suspension of CuI (190 mg, 1.00 mmol) in 15 mL THF, was added to a solution of (*E*)-4-chloro-3-penten-2-one (**2-E**; 110 mg, 0.93 mmol) in 15 mL THF at −10 °C over 10 min. After 1.3 h at −5 °C, 100 mL of pentane and 100 mL of aqueous $NaHCO_3$ were added, and the mixture was stirred and filtered to remove solids. The organic layer was separated, washed with brine (4 × 20 mL), dried ($MgSO_4$), and concentrated. The resulting oil was purified by thin-layer chromatography (silica gel, 1:3 ether–hexane) which gave **3-E**: 56 mg (51%); R_f 0.6. The yield of **3-E** determined by GC before workup was 74% (Carbowax 20M, 105 °C, retention time of **3-E** 13.0 min). For **3-E**: ^1H NMR (C_6D_6, 270 MHz) δ 5.63 (m, 1 H), 2.11 (d, J = 1.1 Hz, 3 H), 1.83 (s, 3 H), 1.34 (d, J = 0.9 Hz, 2 H), −0.18 (s, 9 H); ^{13}C NMR (C_6D_6, 15 MHz) δ 196.7, 159.0, 122.9, 34.7, 32.5, 23.1, −0.4; IR (neat) 1682 cm^{-1}; mass spectrum, calcd for $C_9H_{18}OSi$ *m/e* 170.1128, found 170.1128, *m/e* (relative intensity) 170 (1.9), 155 (32.8), 75 (28.5), 73 (100).

Reaction of $[(CH_3)_3SiCH_2]_2CuLi$ with **2-Z** gave a complex mixture of products. NMR indicated the formation of small, roughly equal amounts of **3-E** and **3-Z** together with a larger amount of **4-Z**.

Photoisomerization of (*E*)-4-Methyl-5-(trimethylsilyl)-3-penten-2-one (3-E). A Pyrex NMR tube containing a toluene-d_8 solution of **3-E** (33 mg, 0.19 mmol, in 0.3 mL) under argon was cooled to −76 °C and irradiated with a 450-W, medium-pressure Hanovia lamp. Cis–trans isomerization was monitored by ^1H NMR at room temperature. A photostationary state was reached after 1 h of irradiation. After 3 h of irradiation the ratio of **3-E**/**3-Z** remained 54:46. Integration vs. *p*-di-*tert*-butylbenzene indicated a loss of about 15% of **3-E** and **3-Z** during isomerization. (*Z*)-4-Methyl-5-(trimethylsilyl)-3-penten-2-one (**3-Z**) was identified in solution by its ^1H NMR (toluene-d_8, 100 MHz): δ 5.82 (m, 1 H), 2.50 (s, 2 H), 1.92 (s, 3 H, $COCH_3$), 1.65 (d, J = 1.5 Hz, 3 H, $=CCH_3$), 0.00 (s, 9 H).

When the mixture of **3-E** and **3-Z** in toluene-d_8 was warmed to 34 °C, the slow thermal rearrangement ($k = 1.5 \times 10^{-4}$ s^{-1}, $t_{1/2}$ = 77 min) of **3-Z** to **4-Z** (100% yield by NMR) was monitored by ^1H NMR. **3-E** is stable under these conditions. **4-Z** was identified in solution by its ^1H NMR (toluene-d_8, 100 MHz): δ 5.00 (m, 2 H), 4.90 (m, 1 H), 2.06 (s, 3 H), 1.70 (s, 3 H), 0.08 (s, 9 H).

(*Z*)-2-Methyl-4-(trimethylsiloxy)-1,3-pentadiene (4-Z). 4-Methyl-3-penten-2-one (7 g, 71 mmol) and then $(CH_3)_3SiCl$ (9 mL, 75 mmol) were added to a solution of $TiCl_4$ (0.5 mL) in 20 mL of $N(CH_2CH_3)_3$. After 1 day, hexane (100 mL) was added, and the reaction mixture was filtered. The solvent was evaporated, and the residue was bulb to bulb distilled under vacuum to give 6.1 g [bp <35 °C (0.5 mm)] of a 9.8:1.2:1.0 mixture of 4-methyl-3-penten-2-one/**4-Z**/4-methyl-2-(trimethylsiloxy)-1,3-pentadiene.[18,19] **4-Z** was isolated by preparative gas chromatography (UCON 50LB550X, 115 °C, 9.2 min). For **4-Z**: IR (neat) 3080, 1648 cm^{-1}; ^{13}C NMR (benzene-d_6, 50 MHz) δ 148.1, 140.8, 112.2, 111.2, 23.8, 23.4, 0.8; mass spectrum, calcd for $C_9H_{18}OSi$ *m/e* 170.1127, found *m/e* 170.1128.

Methyl (*E*)-3-Methyl-4-(trimethylsilyl)-2-butenoate (6-E). A mixture of methyl (*E*)- and (*Z*)-3-chloro-2-butenoates (**5-E** and

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[14] Davison, A.; Rakita, P. E. *Inorg. Chem.* **1970**, *9*, 289. Ashe, A. J., Jr. *Tetrahedron Lett.* **1970**, 2105.

[15] Slutsky, J.; Kwart, H. *J. Am. Chem. Soc.* **1973**, *95*, 8678.

[16] Kwart, H.; Barnette, W. E. *J. Am. Chem. Soc.* **1977**, *99*, 614.

[17] Hartwell, G. W.; Brown, T. L. *Inorg. Chem.* **1964**, *3*, 1656.

[18] The reaction of 4-methyl-3-penten-2-one with $(CH_3)_3SiCl$, Et_3N, and $ZnCl_2$ has been reported to give these products, but the products were not completely characterized: *Chem. Abstr.* **1972**, *65*, P5487; Rhone-Poulenc, S. A. Belgian Patent 670 769.

[19] We found that reaction of 4-methyl-3-penten-2-one with lithium diisopropylamide in THF at −78 °C followed by treatment with $(CH_3)_3SiCl$ at room temperature gave a 1:2 mixture of **4-Z** and 4-methyl-2-(trimethylsiloxy)-1,3-pentadiene. See also: Paterson, I. *Tetrahedron Lett.* **1979**, 1519.

5-Z) was prepared by a modification of the procedure used to prepare the corresponding ethyl esters.[20] The isomers were separated by column chromatography (5% ether–95% pentane, silica gel); **5-E** elutes before **5-Z**. For **5-E**: ^{1}H NMR (100 MHz, C_6D_6)[21] δ 5.95 (m, 1 H), 3.23 (s, 3 H), 2.25 (br s, 3 H); IR (pentane) 1735, 1640 cm^{-1}. For **5-Z**: ^{1}H NMR (100 MHz, C_6D_6) δ 5.70 (m, 1 H), 3.33 (s, 3 H), 1.61 (br s, 3 H); IR (pentane) 1750, 1642 cm^{-1}.

A solution of $[(CH_3)_3SiCH_2]_2CuLi$ prepared from $(CH_3)_3SiCH_2Li$ (0.64 g, 6.8 mmol) and CuI (0.65 g, 3.4 mmol) in 25 mL of THF was added by syringe to a solution of **5-E** (0.49 g, 3.6 mmol) in 10 mL of THF at 0 °C. After 15 min at 0 °C and 1 h at room temperature, the reaction mixture was poured into pentane, washed with 2 N HCl and aqueous $NaHCO_3$, dried ($MgSO_4$), and concentrated to give **6-E** (0.57 g, 90%) which was shown to be an 8:1 mixture of **6-E**/**6-Z** by gas chromatography (6 ft column, 10% Carbowax 20 M, 80 °C). A pure sample of **6-E** was obtained by column chromatography (5% ether–95% pentane, silica gel): ^{1}H NMR (270 MHz, C_6D_6) δ 5.65 (m, 1 H), 3.46 (s, 3 H), 2.22 (d, J = 1.1 Hz, 3 H), 1.41 (d, J = 0.7 Hz, 2 H), −0.14 (s, 9 H); IR (pentane) 1725, 1638 cm^{-1}; mass spectrum, calcd for $C_9H_{18}O_2Si$ m/e 186.1075, found m/e 186.1075, m/e (relative intensity) 186 (0.8), 84 (100), 82 (46), 73 (32), 57 (22), 56 (15), 54 (15).

Reaction of $[(CH_3)_3CH_2]_2CuLi$ (3.5 mmol) with **5-Z** (3.5 mmol, 98:2 **Z**/**E**) in THF for 16 h at room temperature led to the isolation of 0.45 g of a mixture of starting material (**5-Z**, 45%) and a 2.3:1 mixture of **6-E** and **6-Z** (50%).

1-Methoxy-1-(trimethylsiloxy)-3-methyl-1,3-butadiene (7). Methyl 3-methyl-2-butenoate (5.7 g, 50 mmol) in 10 mL of THF was slowly added at 0 °C to a solution of lithium diisopropylamide prepared by addition of a hexane solution of n-BuLi (30.5 mL, 1.64 M, 50 mmol) to $HN[CH(CH_3)_2]_2$ (5.0 g, 50 mmol) in 100 mL of THF. $(CH_3)_3SiCl$ (75 mmol) and 2 mL of triethylamine were added at 0 °C. Hexane (100 mL) was added, and the reaction mixture was filtered, concentrated, and distilled under reduced pressure to give an ~1:1 mixture of **7-Z** and **7-E**: 5.2 g (66%); bp 40 °C (0.3 mm). When the distillation of **7** was carried out at 65 °C (1 mm) or if the mixture of **7-Z** and **7-E** was heated to 115 °C for 40 min, isomerization to give a single isomer of **7** was observed. For the thermodynamically favored isomer of **7**: ^{1}H NMR (C_6D_6, 270 MHz) δ 4.90 (br d, J = 2.7 Hz, 1 H), 4.65 (m, J_{CH_3} = 1.4 Hz, J_H = 2.7 Hz), 4.23 (s, 1 H), 3.15 (s, 3 H), 2.00 (dd, J = 1.4 Hz, J' = 0.7 Hz, 3 H), 0.14 (s, 9 H); ^{13}C NMR (15 MHz, C_6D_6, off-resonance decoupled) δ 159.4 (s), 141.9 (s), 110.2 (t), 83.7 (d), 56.5 (q), 25.6 (q), 2.2 (q); IR (hexane) 1660 cm^{-1}; mass spectrum, calcd for $C_9H_{18}O_2Si$ m/e 186.1075, found m/e 186.1075, m/e (relative intensity) 149 (38), 146 (100), 131 (20), 89 (16), 75 (14), 73 (40), 59 (14). The only difference observed between the ^{1}H NMR (C_6D_6) of the two isomers of **7** is the CH_3O resonances which appear at δ 3.15 and 3.12.

Methyl (Z)-3-Methyl-4-(trimethylsilyl)-2-butenoate (6-Z). The decomposition of **7** (150 mg, 0.80 mmol) in toluene-d_8 occurred at 117 °C (NMR yield 46%) (k = 9.7 × 10^{-5} s^{-1}, $t_{1/2}$ = 2.0 h) to give a ~1.1 mixture of **6-Z** and $(CH_3)_3SiOCH_3$. $(CH_3)_3SiOCH_3$ was isolated in 27% yield by preparative gas chromatography (UCON 50 HB 280X, 64 °C) and identified by comparison of NMR and IR spectra and GC retention times with those of an authentic sample. None of **6-E** was detectable by NMR. **6-Z** (40% yield) was isolated by preparative thin layer chromatography (3:7 CH_2Cl_2–hexane, silica gel, R_f 0.3): ^{1}H NMR (270 MHz, C_6D_6) δ 5.67 (br s, 1 H), 3.42 (s, 3 H), 2.46 (br s, 2 H), 1.52 (br d, J = 1.1 Hz, 3 H), 0.05 (s, 9 H); ^{13}C NMR (C_6D_6, 15 MHz) δ 169.0, 161.8, 114.4, 52.0, 29.3 (CH_2Si and CH_3C=), 1.0; IR (pentane) 1730, 1640 cm^{-1}; mass spectrum, calcd for $C_9H_{18}O_2Si$ m/e 186.1075, found m/e 186.1075, m/e (relative intensity) 186 (2.3), 89 (29.7), 82 (100), 77 (30.5), 73 (55.3), 59 (17.9).

6-Z was also obtained by photolysis of **6-E**. A pentane solution of **6-E** in a quartz tube was irradiated in a Srinivasan-Griffin photochemical reactor with mercury lamps (254-nm maximum). The photolysis was followed by gas chromatography which indicated that a photostationary state consisting of a 1.7:1.0 ratio of **6-E**/**6-Z** was established after 16 h. The mixture was separated by thin-layer chromatography (10% ether–pentane, silica gel; R_f 0.5 for **6-E**, R_f 0.3 for **6-Z**), and the components were identified by ^{1}H NMR.

Registry No. **1**, 40988-97-4; **2-E**, 49784-51-2; **2-Z**, 49784-64-7; **2-E**, 76927-58-7; **3-Z**, 76915-31-6; **4**, 76915-32-7; **5-E**, 6372-01-6; **5-Z**, 6214-25-1; **6-E**, 65263-86-7; **6-Z**, 65263-87-8; **7-E**, 76927-59-8; **7-Z**, 76915-33-8; $(CH_3)_3SiCH_2Li$, 1822-00-0; $(CH_3)_3SiCl$, 75-77-4; $(CH_3)_3SiOCH_3$, 1825-61-2; 4-methyl-3-penten-2-one, 141-79-7; 4-methyl-2-(trimethylsiloxy)-1,3-pentadiene, 6651-46-3; methyl 3-methyl-2-butenoate, 924-50-5.

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[20] Jones, D. E.; Morris, R. O.; Vernon, C. A.; White, R. F. M. *J. Chem. Soc.* **1960**, 2349.

[21] For further ^{1}H and ^{13}C NMR see: Brouwer, H.; Stothers, J. B. *Can. J. Chem.* **1972**, *50*, 601.

N-Nitroso Bile Acid Conjugates. 1. Synthesis, Chemical Reactivity, and Mutagenic Activity

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Two *N*-nitroso bile acid conjugates, *N*-nitrosotaurocholic acid (NOTC) and *N*-nitrosoglycocholic acid (NOGC), have been synthesized. Spectral data were consistent with *N*-nitrosamide structures. NOTC and NOGC decomposed in mildly alkaline aqueous solution to give cholic acid and the respective alcohols, 2-hydroxyethanesulfonic acid and glycolic acid. The rates of decomposition for both compounds between pH 7 and 9 indicated a $t_{1/2}$ of ca. 2–4 h at neutral pH. Under simulated gastric conditions, NOTC was formed from taurocholic acid and nitrite. NOTC and NOGC were mutagenic in a bacterial forward mutation assay (*S. typhimurium* TM 677). The results are discussed with respect to the mechanisms of *N*-nitrosamide decomposition.

Cancer of the gastrointestinal tract accounts for a large proportion of the cancers which afflict humans in the United States and other parts of the world.[1] Much attention has been focussed on exogenous sources of carcinogens such as foodstuffs and environmental pollution with comparatively little attention being paid to possible endogenous formation of carcinogens.

One class of chemicals, *N*-nitroso compounds, has been extensively studied in connection with chemical carcino-

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[1] R. Peto, *Nature (London)*, 284, 297 (1980).

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