Mechanism of Migration of the Trimethylsilyl Group during Reactions of Methoxy[(trimethylsilyl)ethoxy]carbene with *N*-Phenylmaleimide and C_{60}

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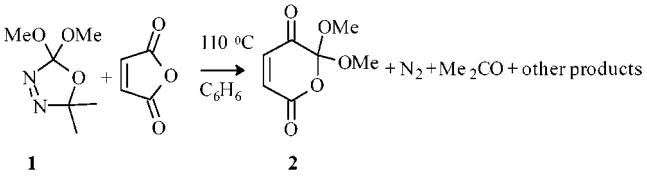
A novel migration of the trimethylsilyl group during reaction of methoxy[(trimethylsilyl)ethoxy]-carbene with *N*-phenylmaleimide (NPM) and with C_{60}, reported earlier, was examined by means of deuterium labeling of the carbene. For the NPM case it was found that the $CD_2CH_2SiMe_3$ group, initially bound to oxygen, became the $CH_2CD_2SiMe_3$ group bound to carbon in the end product. Not only had the trimethylsilylethyl group moved from oxygen to carbon, but the TMS group had also migrated 1,2 along the ethyl chain. For the C_{60} case, complete scrambling of the CD_2 group was observed, strongly implying the involvement of a silacyclopropane carbocation responsible for product formation. The labeling study supports the mechanism that was tentatively advanced earlier for addition to NPM and one of the possibilities suggested for addition to C_{60}.

Introduction

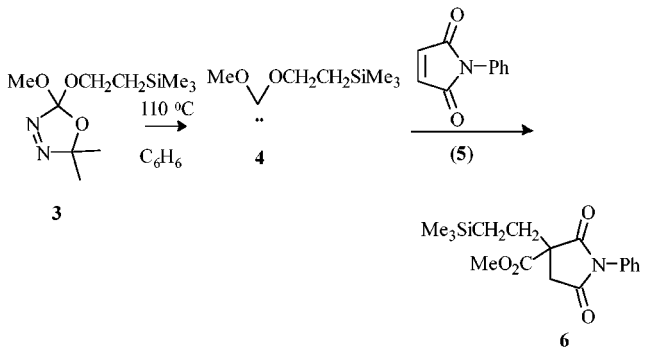
The thermal reaction of dimethoxycarbene, from thermolysis of oxadiazoline **1**, with maleic anhydride was unprecedented[1] affording the product (**2**) of apparent nucleophilic attack of the carbene at a carbon of a carbonyl group, Scheme 1. Products of attack at the CC double bond were not found. Those results led us to examine other dialkoxycarbenes, to determine whether the observed attack (Scheme 1) might be diverted to attack on the C=C bond. It was found that methoxy-[(trimethylsilyl)ethoxy]carbene (**4**), from oxadiazoline precursor (**3**), does indeed react at that bond with *N*-phenylmaleimide (**5**).[2] Moreover, the same carbene gave products of reactions at the C=C bonds of C_{60}.[3] The unexpected major product from **5** was **6**, Scheme 2. We now report a reinvestigation of the reaction by means of deuterium labeling, undertaken in order to discover the fates of the methylene groups of the trimethylsilylethoxy portion. A tentative mechanism advanced after the initial discovery[2] requires migration of the TMS group from one methylene group to the other, as well as inversion at both methylene carbons.

Scheme 1



1 2

Scheme 2



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Results and Discussion

Deuterium-labeled oxadiazoline **9** was prepared by means of the exchange method,[4] from **7** and deuterated trimethylsilylethanol **8**, Scheme 3. The latter was prepared from commercial methyl (trimethylsilyl)acetate (Aldrich) by reduction with lithium aluminum deuteride.

Thermolysis of **9** in the presence of NPM (**5**) afforded **10**, in which the label was clearly in the position shown, as indicated by the ^{1}H NMR spectrum, which was identical to that of **6**[2], save for the absence of a multiplet at $\delta = 2.08$, and a more narrow multiplet for the CH_2 group, coupled to $SiCD_2$ in **10** rather than to $SiCH_2$ as in **6**. This result shows that the trimethylsilyl group does indeed migrate from one CH_2 group to the other of the two-carbon chain, as initially postulated,[2] but it leaves the stereochemical question about inversion unanswered.

(1) Pole, D. L.; Warkentin, J. *Liebigs Ann.* **1995**, 1907.
(2) Pole, D. L.; Sharma, P. K.; Warkentin, J. *Can. J. Chem.* **1996**, *74*, 1335.
(3) González, R.; Wudl, F.; Pole, D. L.; Sharma, P. K.; Warkentin, J. *J. Org. Chem.* **1996**, *61*, 5837.
(4) Kassam, K.; Pole, D. L.; El-Saidi, M.; Warkentin, J. *J. Am. Chem. Soc.* **1994**, *116*, 1161.

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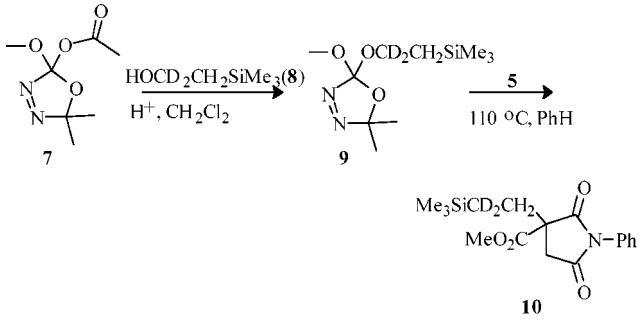
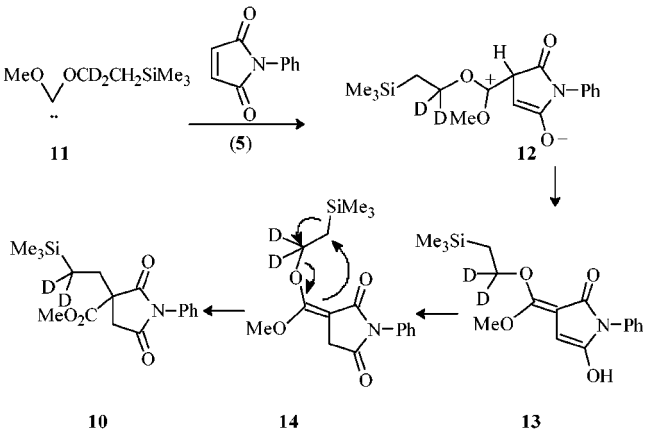
Scheme 3



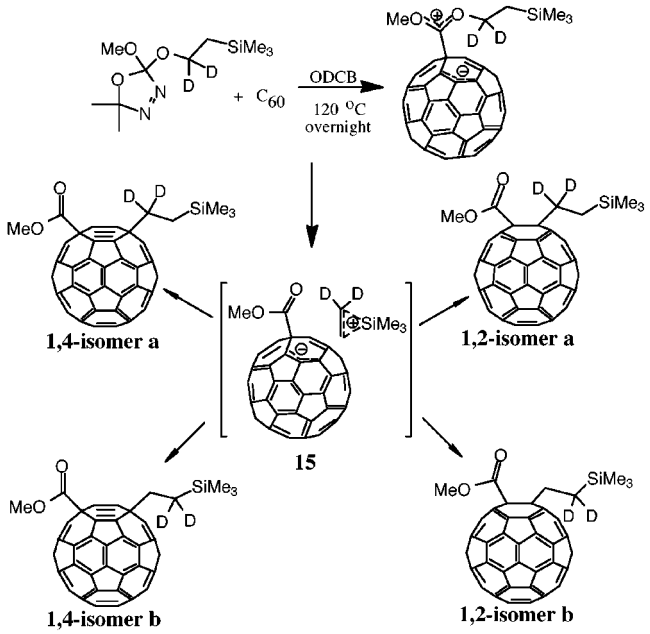
Scheme 4



The novel mechanism in Scheme 4 is proposed to account for the contiguous methyl ester and timethylsilylethyl groups at C3.[2] Its essential features are nucleophilic attack of the carbene (**11**), in the Michael sense, to afford a dipolar intermediate **12**. That species tautomerizes to **14**, possibly by 1,4-sigmatropic migration of H to generate **13**, which is the enolic isomer of ketene acetal **14**. From **14**, a six electron concerted process results in **10** in which the TMS group is bonded to CD_2, the whole TMS-ethyl group is bonded to the succinimidyl ring and a methyl ester function has emerged. The result of deuterium labeling lends credence to the proposed mechanism.

Reaction of **9** with C_{60} by the published procedure[3] for **3** produced a difficult-to-separate mixture of the 1,2- and 1,4-addition products (see Scheme 5). We were able to obtain the 1,2-isomers pure but were unable to attain the 1,4 isomers without 1,2-isomer contamination. Figures 1 and 2 are the ^{1}H NMR spectra of the 1,2-isomer and the mixture of 1,2- and 1,4- isomers, respectively. The nondeuterated derivative of both isomers showed[3] multiplets with the respective chemical shifts, whereas the 1,2-isomer of the deuterated sample shows only broad singlets at 1.47 (1,2-isomer a) and 3.45 (1,2-isomer b) ppm, respectively. On the other hand, the 1,4-isomers, as a result of lower symmetry,[3] exhibit quartets centered at 1.51 (1,4-isomer a) and 3.12 ppm (1,4-isomer b), respectively. These results are consonant with the intermediacy of the ion pair intermediate **15** depicted in Scheme 5. With the results of this research, we can rule out one of the proposed mechanisms[3] and have more evidence for the other (analogous to Scheme 5). Just as in the case of the addition to NPM (Scheme 3, above), in this case the mechanistic description of Scheme 5 would be more complete with stereochemical labeling. In its absence we cannot make proposals regarding the lifetime or nature (tight ion pair?) of **15**.

Scheme 5



Experimental Section

Alcohol 8. To an ice-cold solution of ethyl (trimethylsilyl)acetate (1.5 g, 9.4 mmol) in dry ether (30 mL) under argon was added, in portions over a period of 20 min, $LiAlD_4$ (0.92 g, 22 mmol). The resulting mixture was heated at reflux for 5 h before it was cooled back to ca. 0 °C with ice. Water (0.3 mL), 10% aqueous NaOH (0.5 mL), and water (0.6 mL) were added successively. The resulting suspension was filtered and the filtrate was washed three times with THF (3 × 15 mL). The combined filtrate was concentrated in vacuo to afford **8** as a colorless, viscous oil, 0.81 g, 72%. ^{1}H NMR ($CDCl_3$) δ: 0.08 (s, 9H), 2.05 (br s, 2H), 2.80 (s, 1H, OH).

Oxadiazoline 9. Oxadiazoline **9** was prepared by the acid-catalyzed exchange method.[4] To a suspension of **8** (0.80 g, 6.7 mmol) and 2-acetoxy-2-methoxy-5,5-dimethyl-Δ^3-1,3,4-oxadiazoline (**7**) of 68% purity (1.84 g, 6.69 mmol of oxadiazoline) in dry methylene chloride (50 mL) were added dry molecular sieves (4A°, 5 g) and *p*-toluenesulfonic acid (125 mg, 0.66 mmol). The resulting mixture was stirred at room temperature for 15 h before it was filtered, and the filtrate was concentrated in vacuo. The yellow oil that remained was subjected to flash chromatography (silica gel, ether/hexane = 1:6) to afford **9** as a colorless oil, 0.528 g, 38%: R_f (ether/hexane = 1:6) 0.38; ^{1}H NMR ($CDCl_3$) δ 0.02 (s, 9H), 0.95 (br s, 2H), 1.60 (s, 6H), 3.44 (s, 3H).

***N*-Phenylsuccinimide 10.** A solution of **9** (0.10 g, 0.45 mmol) and *N*-phenylmaleimide (0.086 g, 0.50 mmol) in dry benzene (5 mL) in a sealed tube was heated at 110 °C for 24 h. Removal of the solvent and chromatography of the residue (Chromatotron, 1 mm plate, 30% ethyl acetate in hexane) gave **10** (50 mg, 33%) as a yellow solid: mp 125−127 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.27 (s, 9H), 0.97 (m, 2H), 1.54 (s, 6H), 3.40 (s, 3H), in excellent agreement with the spectrum of the unlabeled analogue[2] except for the missing multiplet at δ = 3.67−3.86 and the deuterium coupling in the multiplet at δ = 0.97.

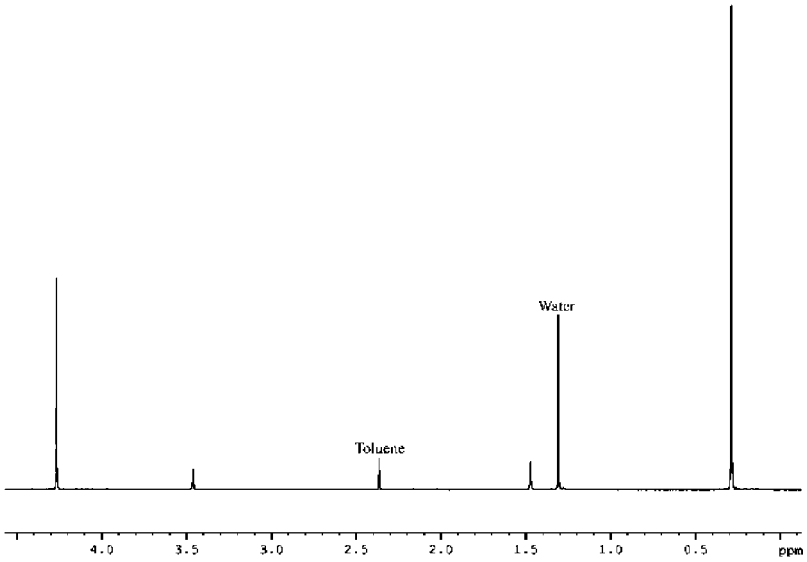


Figure 1. ^{1}H NMR spectrum of 1,2-isomers.

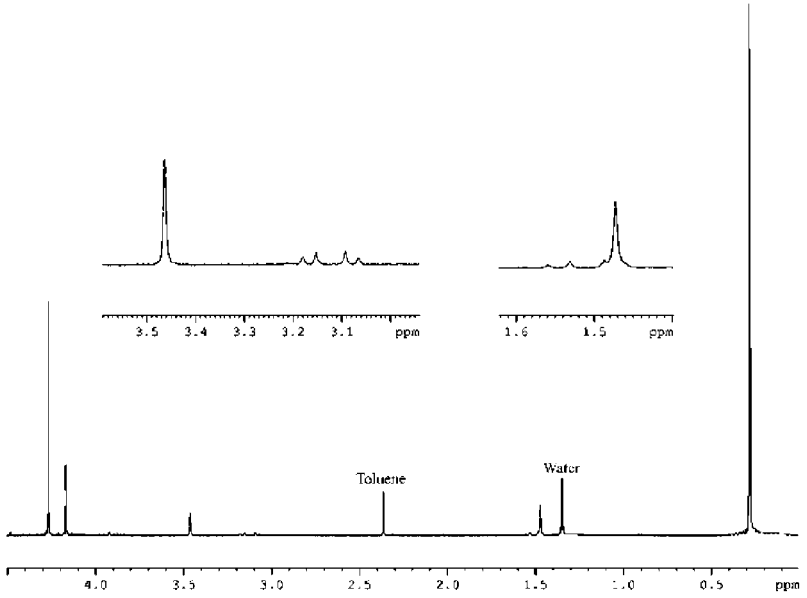


Figure 2. ^{1}H NMR spectrum of mixture of 1,2-and 1,4-isomers.

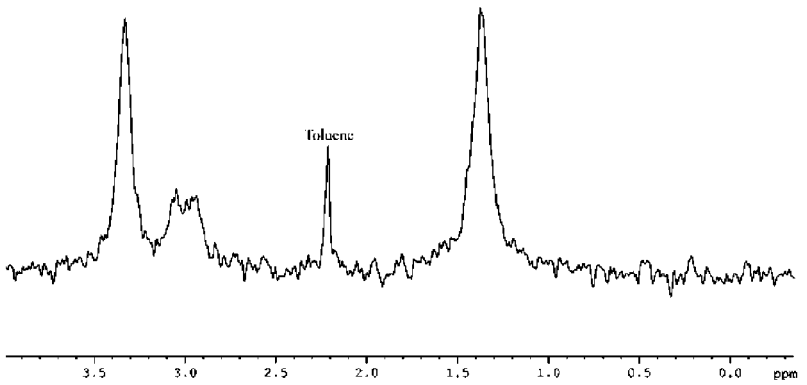


Figure 3. ^{2}H NMR Spectrum of mixture of 1,2- and 1,4-isomers.

Thermolysis of 9 in the Presence of C_{60}. A vacuum-degassed solution of C_{60} (250 mg, 0.34 mmol) and 2-methoxy-2-[(trimethylsilyl)ethoxy]oxadiazoline **9** (85 mg, 0.35 mmol) in 20 mL of anhydrous 1,2-dichlorobenzene, in a sealed tube, was heated at 120 °C for 24 h. After removal of the solvent, the residue, dissolved in the minimum amount of carbon disulfide, was subjected to flash chromatography on silica gel. After elution with 50 mL of carbon disulfide to separate unreacted C_{60}, the eluent was changed to cyclohexane/toluene (95:5) to elute

the addition products. The solvents were evaporated, and the mixture of isomeric addition products was precipitated from toluene with methanol.

The mixture of isomers was separated by preparative HPLC using a Waters 600 pump, a semipreparative Cosmosil Buckyprep column and a Waters 996 Photodiode Array detector. The 1,2-isomers were isolated by eluting with a solution of 25% toluene in hexane at 5 mL/min. We were unsuccessful in isolating the pure 1,4-isomers, but could obtain a mixture of the 1,2- and 1,4-isomers under the same conditions.

1,2-Isomer A: ^{1}H NMR (500 MHz, CS_2) δ (ppm) 4.27 (s, 3H), 1.47 (s, 2H), 0.29 (s, 9H); ^{2}H NMR (153 MHz, $CHCl_3$/toluene-d_8) δ (ppm) 3.33.

1,2-Isomer b: ^{1}H NMR (500 MHz, CS_2) δ 4.27 (s, 3H), 3.46 (s, 2H), 0.29 (s, 9H); ^{2}H NMR (153 MHz, $CHCl_3$/toluene-d_8) δ (ppm) 1.37.

1,4-Isomer a: ^{1}H NMR (500 MHz, CS_2) δ (ppm) 4.17 (s, 3H), 1.51 (dd, J = 14.04 Hz, J = 21.97 Hz, 2H), 0.28 (s, 9H); ^{2}H NMR (153 MHz, $CHCl_3$/toluene-d_8) δ (ppm) 3.05.

1,4-Isomer b: ^{1}H NMR (500 MHz, CS_2) δ (ppm) 4.17 (s, 3H), 3.12 (dd, J = 13.43 Hz, J = 30.21 Hz, 2H), 0.28 (s, 9H); ^{2}H NMR (153 MHz, $CHCl_3$/toluene-d_8) δ (ppm) 1.37.

Conclusions

The remarkable rearrangement of a trimethylsilyl group in reactions of methoxy[(trimethylsilyl)ethoxy]-carbene with *N*-phenylmaleimide and C_{60} was placed on firmer ground by deuterium labeling. For the NPM case, it was found that the $CD_2CH_2SiMe_3$ group, initially bound to oxygen, became the $CH_2CD_2SiMe_3$ group bound to carbon in the end product. Not only had the trimethylsilylethyl group moved from oxygen to carbon, but the TMS group had also migrated 1,2 along the ethyl chain. For the C_{60} case, complete scrambling of the CD_2 group was observed, strongly implying the involvement of a silacyclopropane carbocation responsible for product formation. The labeling study supports the mechanism that was tentatively advanced earlier for addition to NPM and one of the possibilities suggested for addition to C_{60}.

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