

Chemistry of *gem*-Dihalocyclopropanes. XXI. An Example of Competition between 1,3-Insertion and the Vinylcyclopropylidene/Cyclopentenylidene Rearrangement

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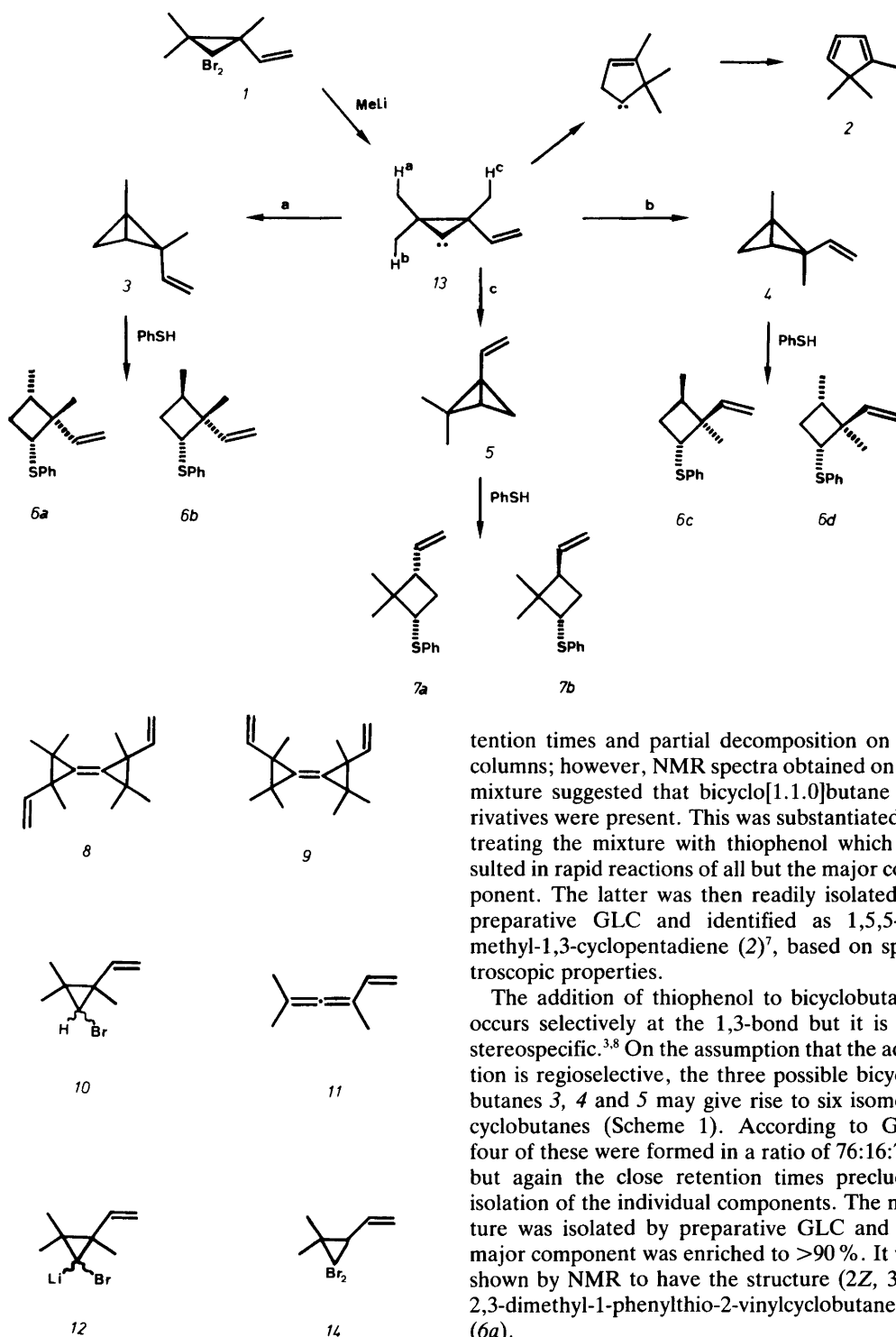
gem-Dibromotrimethylvinylcyclopropane was treated with ethereal methyllithium at four temperatures ranging from -78°C to $+20^{\circ}\text{C}$. At -40°C or higher, 1,5,5-trimethylcyclopentadiene was formed as the main product along with three isomeric bicyclobutanes; the ratio was practically independent of temperature. The compounds are believed to originate from the same intermediate cyclopropylidene by a carbene-carbene rearrangement and 1,3-insertion reactions, respectively. At -78°C a substantial amount of dimers was formed as well, indicating an unusual stabilization of the intermediate α -bromo lithium derivative. No allene was detected in any of the reactions. Possible factors that govern the product distribution are discussed.

Ring opening, insertion and carbene-carbene rearrangement are important reactions of cyclopropylidenes generated from *gem*-dibromocyclopropanes and methyllithium.¹ Knowledge of factors which affect the rates of these reactions may render them more useful synthetically. The effect of substituents on the rate of ring opening to allenes has not been studied extensively;² however, it seems clear that steric interactions have a retarding effect since reactions of tetrasubstituted *gem*-dibromocyclopropanes, containing at least two alkyl groups, afford only minor amounts of allenes; insertion into C–H bonds 1,3-related to the electron deficient carbon predominates.^{3,4} If one of the substituents of the *gem*-dibromocyclopropane ring is a vinyl group, a carbene-carbene rearrangement may take place, *e.g.*, the initially formed vinylcyclopropylidene rearranges to 3-cyclopentenylidene which gives rise to products.⁵ The rate of this rearrangement is to a large extent governed by steric substituent effects.⁶

The cyclopropylidene from 1,1-dibromo-2,3,3-trimethyl-2-vinylcyclopropane (*I*) and methyllithium incorporates the necessary structural features for all the three above-mentioned intramolecular reactions to occur. It was not expected that ring opening should be important, nor that the substituents should actually disfavour the rearrangement as well. However, the 1,3-insertion is not a particularly facile reaction and no results were available which could relate it to the rearrangement. Hence, there was ample reason to study the reactions of *I* with methyllithium.

The preparation of *I* has been described previously.⁶ Reactions with methyllithium were carried out at four temperatures ranging from -78°C to $+20^{\circ}\text{C}$ and at different concentrations. According to capillary gas chromatographic analyses the product from reactions at -78°C was composed mainly of two parts with very different retention times, while at -40°C and above the non-volatile part was absent. At -40°C essentially four compounds were formed in a ratio of 25:14:5:1. The separation of these species by preparative GLC was unsuccessful owing to close re-

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tention times and partial decomposition on the columns; however, NMR spectra obtained on the mixture suggested that bicyclo[1.1.0]butane derivatives were present. This was substantiated by treating the mixture with thiophenol which resulted in rapid reactions of all but the major component. The latter was then readily isolated by preparative GLC and identified as 1,5,5-trimethyl-1,3-cyclopentadiene (2)⁷, based on spectroscopic properties.

The addition of thiophenol to bicyclobutanes occurs selectively at the 1,3-bond but it is not stereospecific.^{3,8} On the assumption that the addition is regioselective, the three possible bicyclobutanes 3, 4 and 5 may give rise to six isomeric cyclobutanes (Scheme 1). According to GLC four of these were formed in a ratio of 76:16:7:1, but again the close retention times precluded isolation of the individual components. The mixture was isolated by preparative GLC and the major component was enriched to >90%. It was shown by NMR to have the structure (2*Z*, 3*Z*)-2,3-dimethyl-1-phenylthio-2-vinylcyclobutane (6*a*).

Thus the ^{13}C DEPT spectrum of *6a* indicates two saturated methines and only one saturated quaternary carbon. Furthermore, the methyl resonance at δ 0.90 in the ^1H spectrum is a 6.8 Hz doublet due to coupling with the proton at δ 2.12. These latter resonances are accordingly assigned to the methyl and proton attached to position 3 of the cyclobutyl ring. A 2D homocorrelated (COSY-90) spectrum together with the multiplet patterns from the 1D spectrum allowed the following assignments to be made. Resonances at δ 2.59 and δ 1.83 are due to the position 4 protons; the former has a 7.8 Hz coupling to the proton at position 1 and an 8.1 Hz couplings of 10.2 Hz and 10.7 Hz, respectively, to these protons. The resonances at δ 5.09 and δ 5.26 are due to the geminal olefinic protons and the relative size of their couplings to the third olefinic proton at δ 6.32 indicates that the δ 5.09 proton is *cis* to the ring.

^1H nuclear Overhauser effects (NOE) observed by the difference technique indicate that this major product is the stereoisomer *6a*. Thus irradiation of the methyl protons at position 3 on the ring gave responses at the olefinic proton α to the ring, but not at the position 1 proton. Irradiation of the methyl protons at position 2 on the other hand gave responses at the olefinic proton *cis* to the ring and at the position 1 proton. There was also a weak response at the position 3 proton; the weakness of this response is presumably caused by domination of the relaxation of this proton by its *gem* methyl protons. Irradiation of the position 3 proton gave a response across the ring to the position 1 proton. All of the above data and the absence of conflicting responses agree only with structure *6a*. Irradiation of the position 1 proton also elicited a response at the downfield proton of position 4, but not at its upfield counterpart. The opposite result was observed on irradiation of the position 3 methyl protons. These observations indicate that the upfield methylene proton is *cis* to the thiophenyl group.

The non-volatile fraction of the product formed at -78°C was shown to consist of at least three components, which also had very close retention times on GLC. They were not separable, but by GLC-MS a strong peak at m/z 216 established the dimeric nature of these compounds. The mixture was isolated by preparative GLC and the NMR spectra suggest the general bi-

cyclopropylidene structures *8* and *9* for the isomers; a resonance at 118 ppm in ^{13}C NMR due to the quaternary olefinic carbons is particularly indicative.⁹ As expected, the concentration of *1* affects the amount of dimers formed. The product contained two additional components in amounts too small for isolation, but according to GLC-MS the compounds are most probably the stereoisomeric monobromides *10*. There were no indications, however, from GLC or spectroscopically that the product contained the allenic compound *11*.

The reaction of *1* with methyllithium initially gives the α -bromocyclopropylithium derivative *12*, the precursor of the cyclopropylidene *13*. When the reaction of *1* at -78°C was quenched six minutes after the addition of methyllithium was completed, an unseparable mixture of the monobromides *Z-10* and *E-10*, in a ratio of 2.6:1, was obtained in 68% yield; the ratio is based on the integrals of the singlets in the ^1H NMR spectrum at δ 2.88 and 3.02, respectively, assigned to the proton adjacent to the bromine atom. For the tetramethyl-substituted analogue of *12* a similar result has been obtained.¹⁰ Nevertheless the observation was unexpected since the loss of lithium bromide from α -bromocyclopropylithium derivatives is usually a fast reaction even at -78°C . Thus formation of the relatively large proportion of dimers, which derive from *12*, is to be expected from reactions carried out at this temperature.

However, in the volatile part of the product the presence of the cyclopentadiene *2* as the major component is not easily accommodated. The substitution pattern should favour 1,3-insertion to bicyclobutanes for the cyclopropylidene *13* and not ring opening to allene. Furthermore, previous observations⁶ indicate that a methyl group *cis* related to the double bond retards the vinylcyclopropylidene to 3-cyclopentenylidene formation; the derivative *14* with methyllithium gave the corresponding allene⁶ exclusively. However, calculations¹¹, kinetic data¹² as well as product distribution studies⁶ indicate that the three competing reactions have comparable energies of activation; therefore, minor substituent effects should influence the rates significantly. According to molecular models the vinyl group of carbene *13* should prefer a *gauche* conformation, which could result in an enhancement of the re-

arrangement rate due to favourable overlap between the π -orbitals of the double bond and the vacant p-orbital of the carbene.

The NMR spectra indicate that the bicyclobutane **5** is the minor component of the mixture. Both isomers **3** and **4** may give rise to the cyclobutane derivative **6a**, but without knowing from which side of the ring system, *endo* or *exo*, the thiophenoxyl radical adds to the 1,3 bond, we cannot distinguish between paths a and b in the scheme which depicts an *endo* mode of addition to the least substituted carbon. In this connection it is interesting to note that *ab initio* calculations indicate a preferred *endo* approach to the bridgehead carbon for both electrophilic¹³ and nucleophilic¹⁴ additions.

Experimental

NMR spectra were acquired on the following instruments; Varian XL300 (300 MHz ¹H, difference NOE, and 75.4 MHz ¹³C), Bruker AM300 (300 MHz COSY), Bruker CXP200 (50.3 MHz ¹³C), Varian EM360 (60 MHz ¹H). The NOE experiments were performed as follows: Low power irradiation was applied to the system, the decoupler was then gated off and the FID was acquired. FID:s were acquired in which the irradiation was both on and off the resonance of interest and the latter were subtracted from the former. The on- and off-resonance FID:s were acquired in cyclical fashion so as to eliminate time-dependent variations. In the interests of selectivity and to avoid selective population transfer effects, broad multiplets were irradiated with lowpower irradiation at several frequencies, the resulting FID:s were added and an appropriately weighted reference FID was subtracted.

Reaction of 1,1-dibromo-2,3,3-trimethyl-2-vinylcyclopropane (1). A stirred solution of **1**⁶ (1.54 g, 6.0 mol) in 50 ml ether cooled to the desired temperature (−78°C to 20°C) was treated dropwise with 5.0 ml methyllithium (1.5 M in ether, 7.5 mmol) during 20 min. The reaction mixture was stirred at the same temperature for an additional 1 h and then 1 h at room temperature before water was added. The organic phase was separated, washed with brine and water and dried (MgSO₄). The product solution was analyzed by capillary GLC (SP 2100, 25 m). Thiophenol (0.22 g, 2.0 mmol) was added to the cooled (10–15°C) solu-

tion of product obtained at −40°C. GLC analysis after 2 h revealed the absence of three of the four peaks at low retention time while new peaks appeared later in the chromatogram. The volatile component was isolated by prep. GLC (20 % SP 2100, 3 m) and identified as 1,5,5-trimethyl-1,3-cyclopentadiene (**2**). IR (CCl₄): 1650, 1610 cm^{−1}. ¹H NMR (60 MHz, CCl₄): δ 1.05 (s, 6H), 1.80 (d, *J* 1.6 Hz, 3H), 5.80 (m, 1H), 6.10 (d, *J* 1.5 Hz, 2H). ¹³C NMR (50.3 MHz, CDCl₃): δ 12.1, 21.8, (CH₃), 52.4 (C), 123.2, 127.6, 145.1 (=CH), 154.2 (=C), GLC/MS (EI): *m/z* 108 (M⁺).

The products from the thiophenol addition were isolated as a mixture by preparative GLC (20% SP 2100 or Apiezon L, 3 m). The major component was identified as (2Z, 3Z)-2,3-dimethyl-1-phenylthio-2-vinylcyclobutane (**6a**).

¹H NMR (300 MHz, CDCl₃): δ 0.90 (d, *J* 6.8 Hz, 3H), 1.23 (s, 3H), 1.83 (q, *J* 10.6 Hz, 1H), 2.12 (d, *J* 8.1 Hz, d, *J* 10.7 Hz, q, *J* 6.8 Hz, 1H), 2.59 (d, *J* 11.1 Hz, t, *J* 7.9 Hz, 1H), 3.55 (d, *J* 7.9 Hz, d, *J* 10.2 Hz, 1H), 5.09 (d, *J* 17.3 Hz, d, *J* 1.5 Hz, 1H), 5.26 (d, *J* 10.9 Hz, d, *J* 1.5 Hz, 1H), 6.32 (d, *J* 10.9 Hz, d, *J* 1.5 Hz, 1H), 7.1–7.3 (m, 5H).

¹³C NMR (75.4 MHz, CDCl₃): δ 15.7 (CH₃ at C3), 23.7 (CH₃ at C2), 35.2 (C-4), 38.7 (C-3), 49.5 (C-1), 50.2 (C-2), 114.7 (=CH₂), 125.8, 128.7, 129.7, 137.2 (phenyl), 138.6 (=CH−). The high boiling fraction formed at −78°C was isolated by preparative GLC (20 % SP 2100, 3 m) and was shown by capillary GLC (SP 1000, 25 m) to consist of at least three components. These were identified as isomeric dimers **8** and **9**.

¹H NMR (60 MHz, CCl₄): δ 1.22 (m, 12H), 1.70 (s, 3H), 1.78 (s, 3H), 4.60–6.0 (m, 6H). ¹³C NMR (50.3 MHz, CDCl₃): δ 15.4–22.3 (CH₃), 28.4–34.0 (C), 109.4–112.7 (=CH₂), 118.4 (=C), 141.9–143.2 (=CH−). GLC/MS (EI): *m/z* 216 (M⁺), 201, 188, 186, 173, 159.

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