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Simple and efficient synthesis of bromine-substituted 1,3-dienes and 1,3,5-cycloheptatriene by vacuum pyrolysis of *gem*-dibromocyclopropanes

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Abstract—To establish whether the results obtained by the gas phase pyrolysis of 6,6-dihalobicyclo[3.1.0]hexanes by HeI photoelectron spectroscopy using a high power CW CO_2 laser as a directed heat source can be achieved on a preparatory scale using a modified apparatus, we carried out the gas phase pyrolysis of a few representative *gem*-dibromocyclopropanes such as 1,1-dibromo-2,2,3,3-tetramethylcyclopropane (**1**), 1,1-dibromo-2,2-dimethyl-cyclopropane (**2**), 1,1-dibromo-*cis*-2,3-dimethylcyclopropane (**3**), 1,1-dibromo-*trans*-2,3-dimethylcyclopropane (**4**), 6,6-dibromobicyclo[3.1.0]hexane (**5**) and 7,7-dibromobicyclo-[4.1.0]heptane (**6**). Except 7,7-dibromobicyclo[4.1.0]heptane, that gave 1,3,5-cycloheptatriene in 72% yield at 525°C, **1**, **2**, **3**, **4** and **5** readily lose HBr at 400–560°C in the gas phase to produce β-bromo-1,3-dienes in high chemical yields and purity. The dienes are potentially useful starting substrates for the Diels–Alder reactions.

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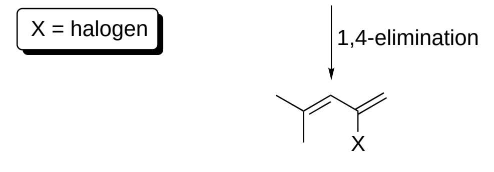
gem-Dihalocyclopropanes constitute a very important class of compounds in organic synthesis due to their wide spectrum of specific chemical reactivity.[1] These valuable transformations include: (i) generation of divalent carbon species, i.e. cyclopropylidenes by the α-elimination of molecular halogen which ultimately isomerize by ring opening to form allenes[2] (in the absence of any carbene trapping agents); (ii) loss of hydrogen halide by β-elimination to produce cyclopropenes which can undergo nucleophilic addition,[3] tautomerization[4] or ring opening;[5] (iii) 1,4-dehydrohalogenation to give halogen substituted 1,3-dienes[6,7] if hydrogen atoms are present in an appropriate exocyclic positions (Scheme 1). A facile ring opening of *gem*-dihalocyclopropanes with or without electrophilic and nucleophilic reagents to give β-bromoallylic compounds is a very useful synthetic method for extending the carbon chain of olefins, which leads to several molecules otherwise difficult to access. The so called 'cyclopropyl-allyl transformation' always produces β-bromoallyl bromides and occasionally β-bromo-1,3-dienes in good yield.[8] A versatile chemical intermediate 1,3,5-cycloheptatriene has been prepared by the thermal rearrangement of 7,7-dichloro- and 7,7-dibromonorcaranes.[9] It is evident from the literature that the ring opening process depends on whether it is carried out neat, in solution or in the gas phase. Therefore, this transformation becomes interesting from both a synthetic and mechanistic point of view.



Scheme 1.

Keywords: vacuum pyrolysis; *gem*-dibromocyclopropanes; β-bromo-1,3-dienes; 1,3,5-cycloheptatriene.

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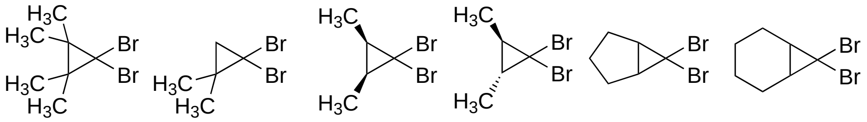
To facilitate the preparation and detection of highly reactive transients, we interfaced a tuneable, high-power CW CO_2 laser with a modified locally built ultraviolet photoelectron spectrometer (UPS). The focussed laser beam was used as a directed heat source to produce a short (1–2 mm), hot contact zone at the tip of a 3 mm OD diameter quartz tube constricted to an ID of 1 mm. The temperature of the nozzle was altered by tuning the laser to an appropriate line. Our interest in preparing and detecting the highly reactive distorted cyclical allene 1,2-cyclohexadiene led us to use this CO_2 laser/UPS apparatus—its first application to research in this field—to study the gas phase (10^{-2} to 10^{-3} Torr) pyrolysis of 6,6-dihalobicyclo[3.1.0]hexanes. We chose to study these compounds because cleavage of the Cl–C5 bond followed by extrusion of dihalogen—the reaction could be concerted—is a possible route to the 1,2-diene. This work led us to discover a very selective generation of β-halo-1,3-dienes.[10] This finding motivated us to exploit the synthetic utility of this technique by synthesising a few representative β-bromo-1,3-dienes at preparatory scales with relatively high chemical purity using an electrically heated furnace. In this article, we wish to report the results of our study on the gas phase pyrolysis of a representative group of *gem*-dibromocyclopropanes and selective trapping of pyrolysates based on their boiling points.

We selected six representative *gem*-dibromocyclopropanes. These *gem*-dibromocyclopropanes (**1**–**6**) were prepared by reacting the dibromocarbene (generated in situ from $CHBr_3$ and *tert*-BuOK) with corresponding olefins following a procedure reported in the literature (Scheme 2).[11]

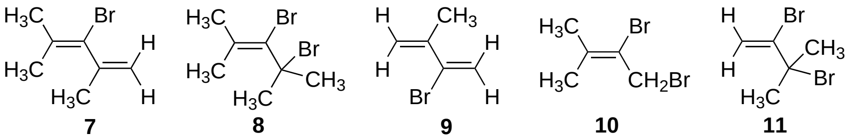
1,1-Dibromo-2,2,3,3-tetramethylcyclopropane (**1**) underwent very clean and quantitative pyrolysis at 500°C to yield 3-bromo-2,4-dimethyl-1,3-pentadiene (**7**) in excellent chemical yield and purity (Scheme 3). There were no traces of any ‘cyclopropyl-allyl’ rearrangement product, 2,3-dibromo-2,4-dimethylpent-3-ene or other products. Upon pyrolysis at 500°C, 1,1-dibromo-2,2-dimethylcyclo-propane (**2**) also produced 2-bromo-3-methyl-1,3-butadiene (**9**) as a sole product. Interestingly, it afforded 1,2-dibromo-3-methyl-2-butene (**10**) in 60% chemical yield at 195–210°C under neat condition.[12] This observation clearly suggests that dehydrobromination occurs in concert with ring opening in the gas phase.

The thermolysis of 1,1-dibromo-*cis*-2,3-dimethylcyclopropane (**3**) at 510°C afforded a mixture (*cis* and *trans*) of 1,3-dienes and 3-bromo-1,3-pentadienes (**12** and **13**) as major products in the ratios of 4:1 along with 15–20% β-bromoallylic bromide and 2,3-dibromopent-3-ene (**14**) (Scheme 4). The stereochemistry of the major diene was established by ^1H NMR spectroscopy using the nuclear Overhauser enhancement (NOE) technique. The irradiation at C_4-H (δ 6.05 ppm) enhanced the signal intensities of the C_2-H (δ 6.32 ppm) and the C_4-CH_3 (δ 1.89 ppm), which suggests that the methyl protons and olefinic protons are closer to C_4-H in space. When C_2-H (δ 6.32 ppm) was irradiated, only resonance enhancement at C_4-H (δ 6.05 ppm) was observed, not at C_4-CH_3 (δ 1.89 ppm). These experiments established the geometry of the major diene in which the methyl group and the bromine are oriented *cis* to each other. In contrast to Sandler’s observation, when 1,1-dibromo-*cis*-2,3-dimethylcyclopropane (**3**) was heated neat at 125–130°C for 72 h under a nitrogen atmosphere only 2,3-dibromopent-3-ene (**14**) was formed as a major product (80%), as seen by ^1H NMR spectroscopy, the remaining being unrearranged starting material. The amount of 1,3-diene formed was <2–3%. Sandler reported the formation of only tars at 150°C for 3 h when **3** was heated neat.[13]



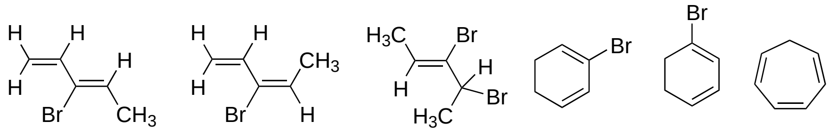
1 **2** **3** **4** **5** **6**

Scheme 2.



7 **8** **9** **10** **11**

Scheme 3.



12 **13** **14** **15** **16** **17**

Scheme 4.

Table 1. Gas phase thermolysis of *gem*-dibromocyclopropanes[15,16]

Entry	*gem*-Dibromocyclopropane	Pyrolysis temp./trap temp. (°C)	Product	Yield (%)
1	**1**	500/−40 to −50	**7**	90
2	**2**	500/−60	**9**	96
3	**3**	560/−65	**11** and **12**	83
4	**4**	500/−50 to −60	**11** and **12**	75
5	**5**	435/−40 to −60	**14** and **15**	85
6	**6**	525/−55 to −65	**17**	72

Similar results were obtained when 1,1-dibromo-*trans*-2,3-dimethylcyclopropane (**4**) was pyrolysed under identical conditions. When it was heated neat at 130–140°C under a nitrogen blanket, it also afforded the same 2,3-dibromopent-3-ene (**14**) in 60% yield as obtained from the *cis*-cyclopropane precursor. The only notable difference between *cis* and *trans* compounds was that the 1,1-dibromo-*trans*-2,3-dimethyl-cyclopropane (**4**) underwent rearrangement much slower and less clean in comparison with the 1,1-dibromo-*cis*-2,3-dimethylcyclopropane (**3**). Again, the formation of only tars was reported when the *trans* compound was heated at 150–170°C for 3 h.

It was of interest to examine several bicyclic systems such as 6,6-dibromobicyclo[3.1.0]hexane (**5**) and 7,7-dibromobicyclo[4.1.0]heptane (**6**), mainly because of the fact that the reactivity of such fused systems depends upon the ring strain with varied ring size. When 6,6-dibromobicyclo-[3.1.0]hexane (**5**) was pyrolysed at 435°C, a mixture of 2-bromo-1,3-cyclohexadiene (**15**) and 1-bromo-1,3-cyclohexadiene (**16**) were obtained along with a small amount of 2,3-dibromocyclohexene. 6,6-Dibromobicyclo[3.1.0]hexane has been known to rearrange to 2,3-dibromocyclohexene during distillation.

As expected, 7,7-dibromobicyclo[4.1.0]heptane (**6**) was observed to be thermally much more stable in comparison with the 6,6-dibromobicyclo[3.1.0]hexane (**5**). At 443°C, **6** underwent only partial pyrolysis, as evident by the presence of 65% starting material in the trap along with 1,3,5-cycloheptatriene (**17**) (15%) and a small amount of other isomeric bromocycloheptadienes by ^{1}H NMR spectroscopy. When the thermolysis was carried out at 525°C, 1,3,5-cycloheptatriene (**17**) was obtained as a sole product in 72% chemical yield. The ^{1}H NMR spectrum of the pyrolysate trapped did not show any other products such as bromine substituted cycloheptene, cycloheptadiene or toluene. There was an indication of the formation of toluene as reported in the literature in the case of 7,7-dichlorobicyclo-[4.1.0]heptane.[14] The results of the pyrolysis reactions of *gem*-dibromocyclopropanes are summarized in Table 1.

In conclusion, we have successfully prepared several synthetically difficult molecules such as 3-bromo-2,4-dimethyl-1,3-pentadiene (**7**), 2-bromo-3-methyl-1,3-butadiene (**9**), 3-bromo-1,3-pentadiene (**12** and **13**), 2-bromo-1,3-cyclohexadiene (**15**) and 1,3,5-cycloheptatriene (**17**) in high chemical yield and purity from easily prepared starting materials using a simple, modified pyrolysis technique in the gas phase. This modified technique also allows us to trap various pyrolysates cleanly and selectively by just adjusting the temperature of the traps by taking advantage of their boiling points. This technique is quite different from the previously mentioned calcium oxide packed electric furnace. These dienes are potentially useful substrates for Diels–Alder and Ene reactions.

Acknowledgements

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15. **Spectral data**: 3-Bromo-2,4-dimethyl-1,3-pentadiene (**7**). ^{1}H NMR ($CDCl_3$): δ 5.00 (m, 1H, C_1-H), 4.90 (m, 1H, C_1-H), 1.85 (s, 6H, C_4-CH_3), 1.81 (s, 3H, C_2-CH_3). 3-Bromo-3-methyl-1,3-butadiene (**9**): ^{1}H NMR ($CDCl_3$): δ 5.80–5.15 (s, with weak allylic and homoallylic couplings, 3H, C_1-H and C_4-H), 1.93 (s, with weak allylic and homoallylic couplings, 3H, C_4-CH_3); ^{13}C NMR ($CDCl_3$): δ 140.87 (C_2), 133.19 (C_3), 120.92 (C_1), 118.61 (C_4), 20.79 (C_5). 1,2-Dibromo-3-methyl-2-butene (**10**): ^{1}H NMR ($CDCl_3$): δ 4.32 (s, 2H, C_1-H), 1.84 (d, 6H, C_3-CH_3). 3-Bromo-1,3-pentadiene (**12**): ^{1}H NMR ($CDCl_3$): δ 6.20–6.40 (dd, 1H, C_2-H), 6.05 (q, 1H, C_4-H), 5.50 (d, *J* 16 Hz, 1H, C_1-H, *trans* to C_2-H), 5.14 (d, *J* 10 Hz, 1H, C_1-H, *cis* to C_2-H), 1.89 (d, *J* 8 Hz, 3H, C_4-CH_3). 3-Bromo-1,3-pentadiene (**13**): ^{1}H NMR ($CDCl_3$): δ 6.52–6.65 (dd, 1H, C_2-H), 6.15 (q, 1H, C_4-H), 5.61 (d, *J* 16 Hz, 1H, C_1-H, *trans* to C_2-H), 5.32 (d, *J* 10 Hz, 1H, C_1-H, *cis* to C_2-H), 1.82 (d, *J* 8 Hz, 3H, C_4-CH_3). 2,3-Dibromopent-3-ene (**14**): ^{1}H NMR ($CDCl_3$): δ 6.20 (q, 1H, C_4-H), 4.90 (q, 1H, C_2-H), 1.85 (d, *J* 8 Hz, 3H, C_4-CH_3), 1.80 (d, *J* 8 Hz, 3H, C_2-CH_3). 2-Bromo-1,3-cyclohexadiene (**14**): ^{1}H NMR ($CDCl_3$): δ 6.05 (m, 1H, C_1-H), 5.70–6.00 (m, 2H, C_3-H and C_4-H), 2.10–2.30 (m, 4H, C_5-H and C_6-H). 1,3,5-Cycloheptatriene (**17**): ^{1}H NMR ($CDCl_3$): δ 6.60 (m, 2H), 6.20 (m, 2H), 5.30–5.50 (m, 2H), 2.25 (t, 2H).
16. **Experimental procedure**: The pyrolysis reactions were conducted in a horizontally oriented electrically heated furnace (11 cm in length) (packed with quartz helices) equipped with valves to control the flow of the starting material. The outlet of the furnace was connected to three U-shaped traps in series. The last trap was immersed in liquid nitrogen and ultimately connected to a high vacuum pump. The precursors were allowed to pass through an electric furnace under high vacuum (3×10^{-2} Torr) and the temperatures of various cooling traps were adjusted on the basis of the boiling points of the pyrolysates. The trapped pyrolysis products were analyzed and characterized by ^{1}H NMR spectroscopy. The chemical purities of the products were also checked by gas chromatography.