

Communications to the Editor

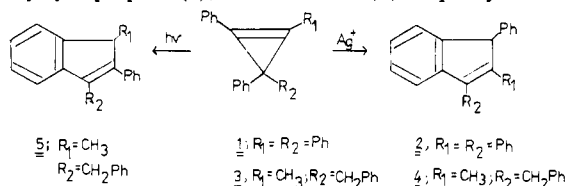
Silver-Promoted Isomerizations of Some Cyclopropene Derivatives

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Received November 10, 1980

Despite the fact that the cyclopropene ring system possesses a remarkably high strain energy (54 kcal/mol),¹ thermal reorganization of its derivatives requires elevated temperatures, usually in excess of 150 °C.² The activation energy for ring opening resides in the vicinity of 35 kcal/mol.^{2,3} A case in point is tetraphenylcyclopropene (**1**), which affords 1,2,3-triphenylindene

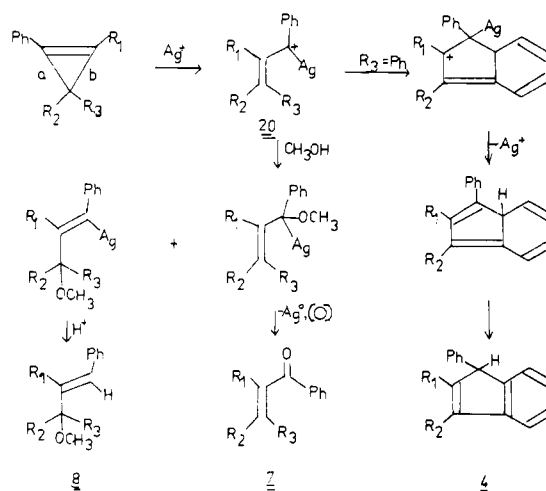


(**2**) when heated above 200 °C.³ In dramatic contrast, exposure of dilute benzene solutions of **1** to catalytic amounts of silver perchlorate at room temperature results within minutes in quantitative conversion to indene **2**. The interaction of metal complexes, notably of silver(I) and rhodium(I), with strained carbocyclic compounds has been a subject of considerable interest in recent years.⁴ These metals catalyze a variety of rearrangements, the course of which depends on the nature of both the organic compound and the metal complex.⁴ In this communication we report that cyclopropene derivatives are rapidly isomerized by trace amounts of silver ion.⁵ We also record that these facile silver-induced reactions differ dramatically from the well-established photochemical rearrangements^{6,7} in that different carbon-carbon bonds are cleaved in the two processes.

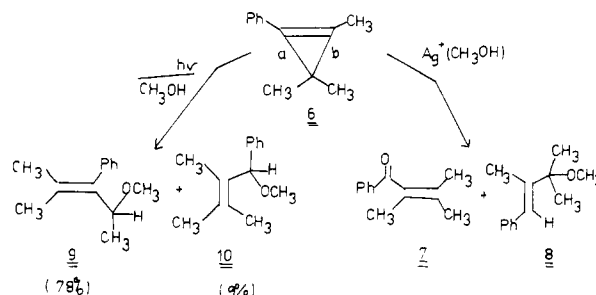
The presence of an alkyl group on the cyclopropene π bond has a significant effect on the regiochemistry of the ring-opening reaction. Thus, treatment of an unsymmetrically substituted cyclopropene such as **3** with 2 mol % of silver perchlorate in benzene at room temperature afforded 1-phenyl-2-methyl-3-benzylindene (**4**) as the exclusive product. In contrast, photolysis of **3** produced the isomeric 1-methyl-2-phenyl-3-benzylindene (**5**) in 90% yield as the major photoproduct.

In order to obtain a better understanding of the factors controlling the regiochemistry of the silver-induced rearrangement, we decided to investigate the isomerization of a system devoid of

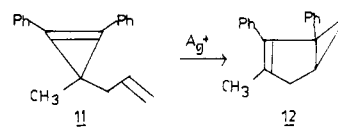
Scheme I



a phenyl group in the 3-position of the cyclopropene ring. Treatment of 1-phenyl-2,3-trimethylcyclopropene (**6**) with a slight excess of silver perchlorate in methanol for 1.5 h at 25 °C gave rise to a mixture of 2,3-dimethyl-1-phenyl-2-buten-1-one (**7**) (55%) and 3-methoxy-2,3-dimethyl-1-phenyl-1-butene (**8**) (45%). The structures of **7** and **8** were established by a comparison of their IR and NMR spectra with authentic samples. In contrast to the silver ion promoted reaction, the only products obtained from the irradiation of **6** in methanol are ethers **9** (78%) and **10** (9%). The distribution of products obtained from the irradiation of **6** corresponds to preferential bond b cleavage and is closely related to results encountered with 3-aryl- and -vinyl-substituted cyclopropenes.^{6,7} It is clear from the above data that the silver-induced rearrangement of an unsymmetrical cyclopropene is not governed by the same electronic considerations which control its photochemical behavior.⁶



Placement of an allyl group on the C₃-position of the cyclopropene ring causes a different mode of behavior to occur on exposure to silver ion. The reaction of 1,2-diphenyl-3-methyl-3-allylcyclopropene (**11**) with a catalytic quantity of silver perchlorate in benzene gave 1,2-diphenyl-3-methylbicyclo[3.1.0]hex-2-ene (**12**) in 85% yield. Similar treatment of closely related 1,3-diphenyl-2-methyl-3-allylcyclopropene (**13**) with trace amounts of silver ion gave indene **14** (90%) and bicyclohexene **15** (10%).



(1) Schleyer, P. von R.; Williams, J. E.; Blanchard, K. R. *J. Am. Chem. Soc.* **1970**, *92*, 2377.

(2) York, E. J.; Dittmar, W.; Stevenson, J. R.; Bergman, R. G. *J. Am. Chem. Soc.* **1972**, *94*, 2882. *Ibid.* **1973**, *95*, 5680.

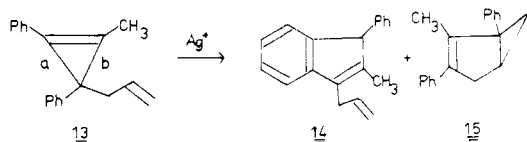
(3) Battiste, M. A.; Halton, B.; Grubbs, R. H. *Chem. Commun.* **1967**, 907.

(4) Bishop, K. C. *Chem. Rev.* **1976**, *76*, 461.

(5) There are a number of examples in the literature dealing with the transition metal promoted rearrangement of cyclopropenes. See (a) Stechl, H. H. *Chem. Ber.* **1964**, *97*, 2681. (b) Leftin, J. H.; Gil-av, G. *Tetrahedron Lett.* **1972**, 3367. (c) Shirafuji, T.; Yamamoto, Y.; Nozaki, N. *Ibid.* **1971**, 4713. (d) Weiss, R.; Schlier, F. C. *Angew. Chem., Int. Ed. Engl.* **1971**, *10*, 811. (e) deWolf, W. H.; von Straten, J. W.; Bickelhaupt, F. *Tetrahedron Lett.* **1972**, 3509. (f) Weiss, R.; Andrae, S. *Angew. Chem., Int. Ed. Engl.* **1973**, *12*, 150. *Ibid.* **1973**, *12*, 152. (g) Landheer, I. J.; deWolf, W. H.; Bickelhaupt, F. *Tetrahedron Lett.* **1974**, 2813. (h) Battiste, M. A.; Friedrich, L. E.; Fiato, R. A. *Ibid.* **1975**, 45. (i) Fiato, R. A.; Mushak, P.; Battiste, M. A. *J. Chem. Soc., Chem. Commun.* **1975**, 869. (j) Monahan, A. S.; Freilich, J. D.; Fong, J. J. *Tetrahedron Lett.* **1970**, 1865. (k) Walker, J. A.; Orchin, M. *Chem. Commun.* **1968**, 1239.

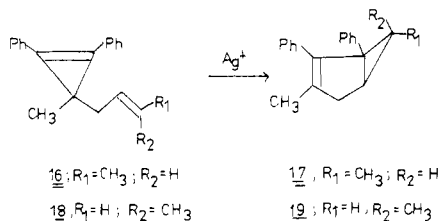
(6) Padwa, A.; Blacklock, T. J.; Getman, D.; Hatanaka, N.; Loza, R. J. *Org. Chem.* **1978**, *43*, 1481. Padwa, A.; Blacklock, T. J. *J. Am. Chem. Soc.* **1977**, *99*, 2345.

(7) Zimmerman, H. E.; Aasen, S. M. *J. Org. Chem.* **1978**, *43*, 1493. Zimmerman, H. E.; Hovey, M. C. *Ibid.* **1979**, *44*, 2331.



The products obtained from the silver-induced reactions are derived from exclusive cleavage of the cyclopropene bond attached to the phenyl group (bond a). This stands in marked contrast to the direct irradiation of 13, which results in predominant bond b cleavage.⁶

At this stage of our studies we decided to investigate the stereochemical course of the silver-induced intramolecular cycloaddition reaction. Treatment of (*E*)-1-(1-methyl-2,3-diphenyl-2-cyclopropen-1-yl)-2-butene (16) with 2 mol % of silver per-

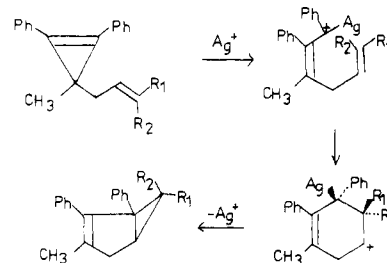


chlorate in benzene gave a 96% yield of *exo*-3,6-dimethyl-1,2-diphenylbicyclo[3.1.0]hex-2-ene (17). Similarly, the reaction of the corresponding *Z*-isomer 18 with silver ion gave *endo*-bicyclohexene 19 as the sole product in 97% yield. These results indicate that complete retention of stereochemistry about the π system has occurred in the silver-catalyzed cycloaddition reaction.

In line with earlier evidence for the intermediacy of a metal-bonded carbonium ion-metal complexed carbene hybrid intermediate in the transition metal promoted rearrangement of strained ring systems,^{8,9} it is tempting to suggest the involvement of a related species in the silver-induced rearrangements of the above systems. Thus, we propose that silver ion behaves as a very specific Lewis acid which attacks the cyclopropene ring to yield argentocarbonium ion 20.¹⁰ Electrocyclization of this intermediate followed by loss of silver ion nicely rationalizes the formation of the indene ring. The clean conversion of 6 in the presence of Ag⁺ into 7 and 8 in methanol can be explained in terms of an oxidation-reduction reaction.¹¹ The reduction of Ag(I) to the metallic state is somewhat reminiscent of results reported by Koser and Faircloth.¹² These workers found that quadricyclane was oxidized and silver ion was reduced to silver metal in the reaction between silver trifluoroacetate and quadricyclane in methanol.¹³ The above results also suggest that the crucial step which dictates the regioselectivity of bond cleavage of the cyclopropene ring is strongly dependent upon relative carbonium ion stabilities. Breakage of bond a would be expected to give rise to the more energetically favorable benzylic argentocarbonium ion.¹⁴

The intramolecular trapping of the ring-opened species by the neighboring double bond provides additional evidence for the

carbenoid character of the intermediate. A reasonable mechanistic option for the intramolecular cycloaddition involves a stepwise attack of the terminal double bond on the argentocarbonium ion so as to generate a six-membered ring. As long as the loss of



silver ion occurs simultaneously with bond making, the cycloaddition will proceed with retention of configuration.

We are continuing to investigate the more intriguing synthetic and mechanistic aspects of these interesting silver ion promoted reactions.

Acknowledgment. We gratefully acknowledge support of this work by the National Science Foundation.

Synthesis of (*S*)- and (*R*)-4-[(Methoxycarbonyl)methyl]-2-azetidinone by Chemicoenzymatic Approach

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Received November 10, 1980

Naturally occurring β -lactam antibiotics which belong to the group carbapenem are still increasing in number¹ and have attracted a great deal of synthetic study because of their unique structure and interesting biological activity.^{1a} However, most of them lead to racemic carbapenem derivatives,^{2,3} and even the chiral synthesis of thienamycin and (-)-homothienamycin consists of multistep reactions to get the azetidinone moiety in low overall yields starting from L-aspartic acid.⁴ The requirements for a simple and high-yielding synthesis of 4-substituted-2-azetidinones having desired absolute configuration⁵ at C-4 are indeed demanding in the exploitation of such highly potential β -lactam antibiotics. We wish to report here an efficient methodology for the preparation of (*S*)- and (*R*)-4-[(methoxycarbonyl)methyl]-

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(1) (a) For thienamycin, olivanic acid, and their analogues, see: "Topics in Antibiotic Chemistry"; Sammes, P., Ed.; Ellis Horwood: New York, 1980; pp 101-138. (b) For PS-5, see: Yamamoto, K.; Yoshioka, T.; Kato, Y.; Shibamoto, N.; Okamoto, K.; Shimauchi, Y.; Ishikura, T. *J. Antibiot.* **1980**, *33*, 796. (c) For carpetimycins, see: Nakayama, M.; Iwasaki, A.; Kimura, S.; Mizoguchi, T.; Tanabe, S.; Murakami, A.; Watanabe, I.; Okuchi, M.; Itoh, H.; Saino, Y.; Kobayashi, F.; Mori, T. *J. Antibiot.* **1980**, *33*, 1388.

(2) (a) Johnson, D. B. R.; Schmitt, S. M.; Bouffard, F. A.; Christensen, B. G. *J. Am. Chem. Soc.* **1978**, *100*, 313. (b) Tufariello, J. J.; Lee, G. E.; Senaratne, P. A.; Al-Nuri, M. *Tetrahedron Lett.* **1979**, 4359. (c) Ponsford, R. J.; Southgate, R. J. *Chem. Soc., Chem. Commun.* **1979**, 845. (d) Kametani, T.; Huang, S.; Yokohama, S.; Suzuki, Y.; Ihara, M. *J. Am. Chem. Soc.* **1980**, *102*, 2060. (e) Cama, L.; Christensen, B. G. *Tetrahedron Lett.* **1980**, *21*, 2013.

(3) An efficient synthesis of *dl*-thienamycin has recently been reported: Melillo, D. G.; Shinkai, I.; Liu, T.; Ryan, K.; Slettinger, M. *Tetrahedron Lett.* **1980**, *21*, 2783.

(4) (a) Salzmann, T. N.; Ratcliffe, R. W.; Christensen, B. G. *Tetrahedron Lett.* **1980**, *21*, 1193. (b) Ikota, N.; Shibata, H.; Koga, K. *Heterocycles* **1980**, *14*, 1077 and references cited therein.

(5) The general necessity of a *5R(6R)* configuration for the biological activity of bicyclic β -lactam antibiotics is well demonstrated. Ernest, I.; Gosteli, J.; Woodward, R. B. *J. Am. Chem. Soc.* **1979**, *101*, 6301 and also see ref 2a.

(8) Gassman, P. G.; Williams, F. J. *J. Am. Chem. Soc.* **1972**, *94*, 7733. Gassman, P. G.; Meyer, G. R.; Williams, F. J. *Ibid.* **1972**, *94*, 7741. Gassman, P. G.; Atkins, T. J. *Ibid.* **1972**, *94*, 7748. Gassman, P. G.; Nakai, T. *Ibid.* **1971**, *93*, 5897. *Ibid.* **1972**, *94*, 2877, 5497.

(9) Paquette, L. A. *Acc. Chem. Res.* **1971**, *4*, 280.

(10) Formation of the argentocarbonium ion may occur via attack on the cyclopropene π bond followed by a rapid ring opening of the transient cyclopropyl cation. Alternatively, silver ion attack could occur on the σ bond to give the argentocarbonium ion directly.

(11) In this case, a full equivalent of silver ion was used.

(12) Koser, G. F.; Faircloth, J. N. *J. Org. Chem.* **1976**, *41*, 583.

(13) It should be pointed out that the production of metallic silver in the conversion of 6 to 7 also leads to the formation of perchloric acid. Control experiments established, however, that the cyclopropene ring system is stable to perchloric acid in methanol under the experimental conditions used. Furthermore, the reaction of 6 in methanol with Ag(I) ion readily occurs in the presence of an excess of triethylamine. These observations indicate that the conversion of 6 to 7 does not proceed via an acid-induced pathway.

(14) The regioselectivity of bond cleavage encountered in the direct irradiation of unsymmetrical cyclopropenes has been attributed to a funneling of the excited state of the cyclopropene to the energy surface of the higher lying vinyl carbene state.^{6,7}