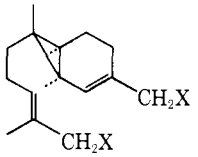
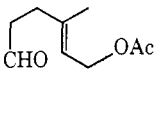
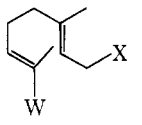
0.92 ppm. Reduction of **21** using a twofold excess of lithium aluminum hydride–aluminum chloride (3:1) in ether at 0° for 10 min and 25° for 1 hr afforded after plc (on silica gel buffered to pH 10 using ether for development) 76% of pure *dl*-sirenin (**1**)[5,6] as a colorless oil, molecular ion found at *m/e* 236.1775 (calcd 236.1776). Vapor phase chromatographic analysis of the bis(trimethylsilyl) derivative of **1** using a 2.5 ft × 0 125 in. column of 3% OV-7 on neutral silanized support at 180° showed a single peak (retention time 5.0 min at 60 cc/min N_2 flow).



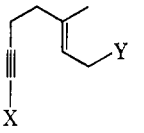
1, X = OH
2, X = H



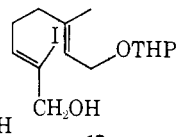
3



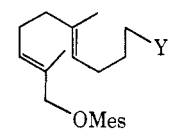
4, W = COOEt; X = OAc
5, W = COOEt; X = OH
6, W = COOEt; X = OTHP
7, W = CH_2OH; X = OTHP
8, W = CH_2OMes; X = OTHP
9, W = CH_2OMes; X = OH
14, W = CH_2OMes; X = Br
15, W = CH_2OMes; X = C≡CCH_2OH



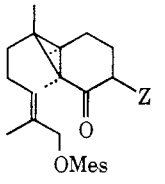
10, X = H; Y = OH
11, X = H; Y = OTHP
12, X = CH_2OH; Y = OTHP



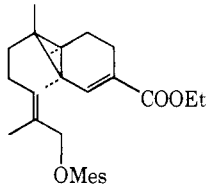
13



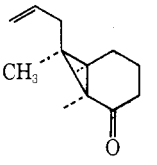
16, Y = CH_2OH
17, Y = COOH
18, Y = $COCHN_2$



19, Z = H
20, Z = COOEt



21



22

The nmr and infrared spectra of synthetic **1** were in complete agreement with reference spectra of natural sirenin kindly provided by Professor H. Rapoport. The nmr spectrum of synthetic **1** (obtained at 100 MHz in chloroform solution) displayed a sharp singlet due to cyclopropyl CH_3 at 0.88 ppm, a broadened peak due to C=CCH_3 at 1.67 ppm, a peak (4 H) due to two carbinyl methylenes at 3.98 ppm, and two olefinic protons at 5.39 (broadened triplet) and 5.82 (broad) ppm, in addition to a complex series of peaks in the region 1–2.2 ppm due to the remaining protons.

Bioassays of synthetic and natural sirenin, kindly performed by Prof. L. Machlis using an approximate (order of magnitude precision) method, indicated comparable biological activity.

A particularly interesting feature of this synthesis of *dl*-sirenin is the efficiency and stereospecificity of the cyclization of the acyclic diazo ketone **18** to the bicyclic ketone **19**. In this connection mention should be made of unpublished work in this laboratory concerning an alternative synthesis of the bicyclo[4.1.1]heptan-2-one system which leads predominantly to the oppostie arrangement of the groups at C-7. Reaction of diphenylsulfonium (1-allyl)ethylide with 2-cyclohexenone[16] produces **22** as the major product.[17]

(16) E. J. Corey and M. Jautelat, *J. Am. Chem. Soc.*, **89**, 3912 (1967).

(17) This work was supported by the National Institutes of Health and the National Science Foundation.

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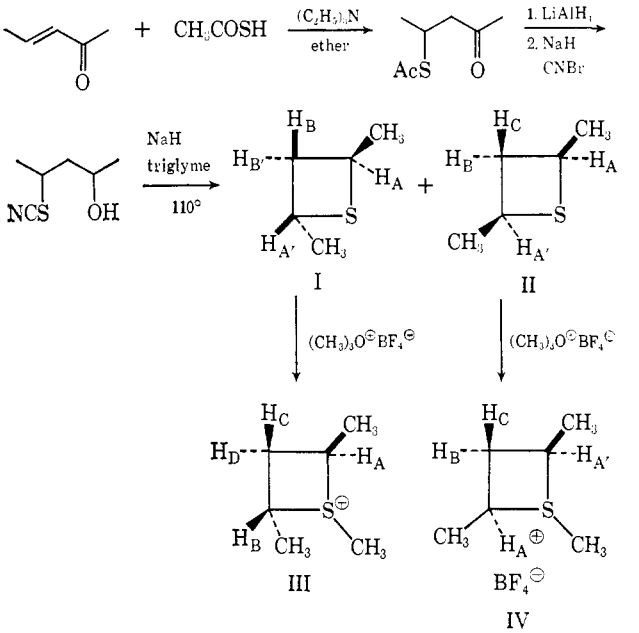
Stereochemistry of Fragmentation of Thietanonium Salts

Sir:

We wish to report the stereochemistry of an unusual fragmentation reaction of thietanonium salts. Such a study provides insight into the effect of d orbitals on the course of reactions in organosulfur compounds.[1]

We have found that treatment of S-methylthietanonium salts with *n*-butyllithium produces cyclopropanes and *n*-butylmethyl sulfide.[2] To elucidate the nature of this process we examined the behavior of the salts derived from *cis*- and *trans*-2,4-dimethylthietane. Scheme I summarizes the syntheses of the requisite materials.[3]

Scheme I



The stereochemistry of the thietanes was assigned utilizing nmr. The *cis* isomer shows the ring protons as

(1) For our previous paper in this series, see B. M. Trost, R. W. LaRochelle, and R. C. Atkins, *J. Am. Chem. Soc.*, **91**, 2175 (1969).

(2) A report of the treatment of thietane with *n*-butyllithium has appeared. A 11% yield of lithium *n*-butylmercaptide was detected and cyclopropane was assumed to be the second product; see F. G. Bordwell, H. M. Andersen, and B. M. Pitt, *ibid.*, **76**, 1082 (1954). Reaction of our thietanes with *n*-butyllithium did not produce any detectable amounts of cyclopropanes.

(3) This mode of synthesis represents a modification of the scheme of S. Searles, Jr., H. R. Hays, and E. F. Lutz, *J. Org. Chem.*, **27**, 2828 (1962).

Table I. Nmr of Thietanes and Salts[a]

Compound	H_A	H_B	H_C	H_D	J_{AB}	J_{AC}	J_{BC}	J_{BD}	J_{CD}
I	3.62	2.61	...	...	6.9	...	...	...	...
II	3.58	2.99	2.13	...	7.3	8.2	11.0	...	...
III	4.63	3.98	3.19	2.76	...	4.0	4.0	8.5	13.0
IV	4.29	3.46	2.51	...	9.0	9.5	12.5	...	...

[a] All chemical shifts are expressed in ppm relative to internal TMS. Coupling constants are expressed in Hz.

an AA'BC pattern, whereas the *trans* isomer shows these protons as an AA'BB' pattern. Treatment of each sulfide with trimethyloxonium fluoroborate at −30° generated the corresponding S-methylthietanonium fluoroborates.

It is interesting to note that inversion at sulfur in the thietanonium salts does not occur up to the decomposition temperature (80°).

Treatment of the *trans* salt with *n*-butyllithium produced the *cis*-dimethylcyclopropane with a high degree of stereospecificity, whereas treatment of the *cis* salt produced the *trans*-cyclopropane (see Table II and Scheme II). The first step in this reaction most reasonably is attack at sulfur by the organolithium to produce the pentacoordinate sulfur species V.[1] Such attack has been established as the prime reaction of electron-deficient sulfur species with organolithiums. Three possible modes of cleavage exist. A direct fragmentation (A) to cyclopropane is thermally allowed in a conrotatory fashion predicting the inversion of configuration. Alternatively (B), cleavage to trimethylene followed by bond formation produces cyclopropane.[4,5] Extended Hückel calculations indicate the antisymmetric state which should close in a conrotatory fashion to be the lower in energy. The third mechanism (C) involves ligand explusion from V with retention of configuration at the formed carbanion followed by SN2 displacement again leading to inversion in formed cyclopropane.

That mechanism C is not operative derives mainly from a comparison to the reaction of *meso*- and *dl*-2,4-dibromopentanes. Each dibromide was allowed to react with *n*-butyllithium under the conditions of the thietanonium salt decomposition. Table III summarizes the relevant data. That metal–halogen exchange has occurred extensively under these conditions is evidenced by the fact that 2-bromopentane is one of the major products isolated. It arises by protonation of the initially formed 2-lithio-4-bromopentane. That metal–halogen exchange occurs with a high degree of retention of configuration is supported by previous

Table II. Stereochemistry of Fragmentation Generating 1,2-Dimethylcyclopropane

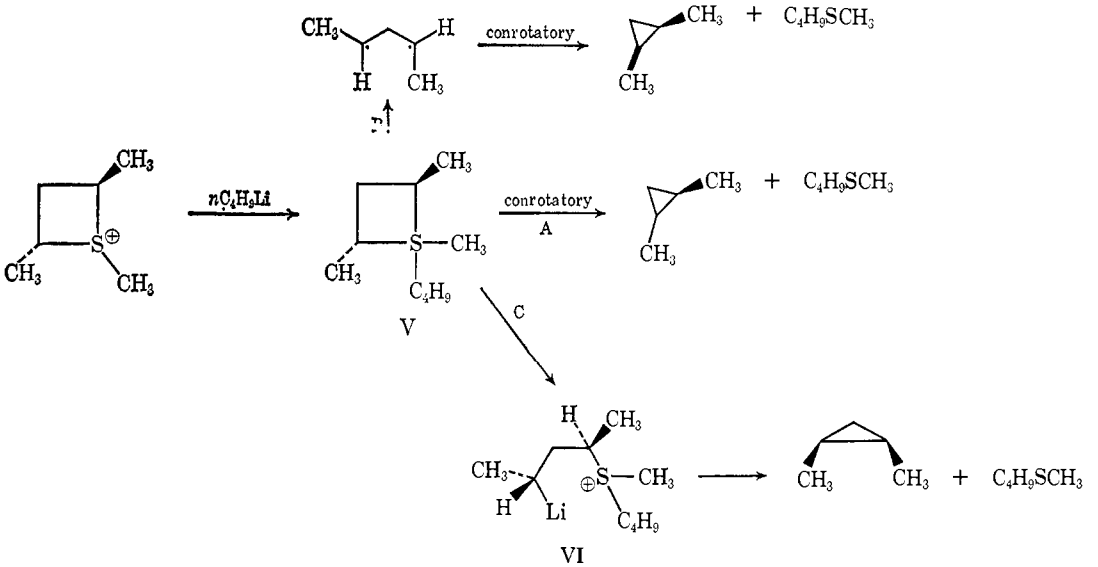
Starting salt	Temp, °C	% *cis*-cyclopropane	% *trans*-cyclopropane
III[a]	−30	86.9	13.1
III[b]	−78	88.6	11.4
IV[c]	−30	10.0	90.0
IV[d]	−78	8.5	91.5

[a] Total yield of cyclopropanes was 22%. [b] Total yield of cyclopropanes was 23%. [c] Total yield of cyclopropanes was 29%. [d] Total yield of cyclopropanes was 27%.

Table III. Reactions of 2,4-Dibromopentane

Starting isomer	Temp, °C	% *cis*-cyclopropane	% *trans*-cyclopropane	% yield
meso	−30	82.2	17.8	2.3
meso	−78	90.4	9.6	1.7
dl	−30	24.3	75.7	7.0
dl	−78	16.5	83.5	5.6

Scheme II



(4) For the stereochemistry of ring closure of trimethylene at 200°, see R. J. Crawford and A. Mishra, *J. Am. Chem. Soc.*, **88**, 3963 (1966).

(5) For a theoretical treatment of trimethylene, see R. Hoffmann, *ibid.*, **90**, 1475 (1968).

work[6,7] and the data here. In particular, at low temperature the reaction proceeds with a high degree of stereospecificity indicating that the stereochemistry of the starting dibromide is being relatively faithfully translated into the stereochemistry of the product. Considering that bromide is a much better leaving group than dialkyl sulfide,[8] the yields of cyclopropane and the degree of stereospecificity should be higher (or at least comparable) in the bromide cases than in the case of the thietanonium salts.[9] The opposite is observed. Furthermore, the isomer ratio for the thietanonium reactions is practically independent of temperature in our operating range, whereas for the dibromide reaction there is such a dependence. This observation is the opposite of that anticipated for mechanism C. Finally, reaction of 1,2,2,4-tetramethyl-1-thiacyclobutonium fluoroborate with *n*-butyllithium under the same conditions as for III and IV produces 1,2,2-trimethylcyclopropane in yields of 20–30%. The undiminished yields compared to the dimethyl case also suggests the unlikelihood of a displacement mechanism (*i.e.*, C).

Although the above data strongly suggest that mechanism C can be eliminated, it does not allow a distinction to be made between mechanisms A and B. Geometrically, mechanism A seems less likely than B.

Acknowledgment. We wish to express our gratitude to the National Science Foundation for generous support of our program.

(6) (a) R. L. Letsinger, *J. Am. Chem. Soc.*, **72**, 4842 (1950); (b) H. O. House and R. S. Ro, *ibid.*, **80**, 182 (1958), and references therein.

(7) B. M. Trost and S. Ziman, *Chem. Commun.*, 181 (1969).

(8) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp 182–185.

(9) The stereochemistry of cyclopropane formation from the dibromide requires a double inversion process for this 1,3 elimination. Such has been found for a modification of the Ramberg–Bäcklund reaction. See F. G. Bordwell, B. B. Jarvis, and P. W. R. Corfield, *J. Am. Chem. Soc.*, **90**, 5298 (1968).

(10) Alfred P. Sloan Foundation Fellow.

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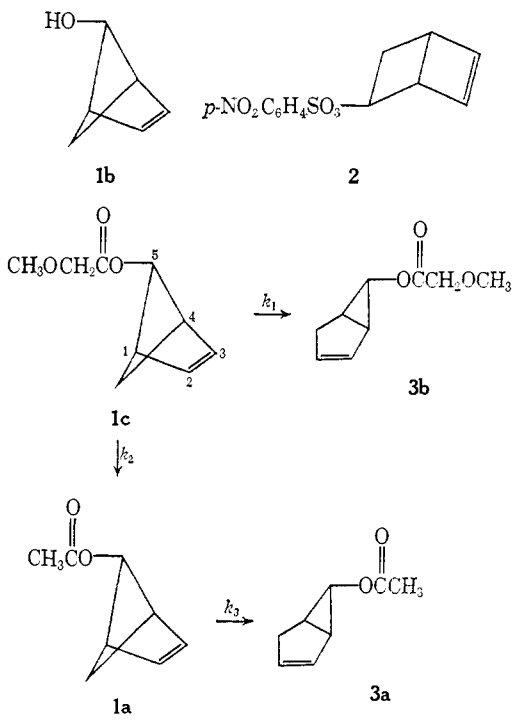
Solvolysis and Thermolysis of *exo*-Bicyclo[2.1.1]hex-2-en-5-ol Derivatives

Sir:

Current interest[1] in the bicyclo[2.1.1]hex-2-ene system has arisen largely from the obvious curiosity on the solvolytic behavior of C-5 derivatives of this system. Our synthesis recently reported[2] has been designed particularly to solve this problem and has provided *exo*-bicyclo[2.1.1]hex-2-en-5-yl acetate (**1a**). We wish to report herein the solvolysis of esters of the alcohol **1b** and, further, the stereochemistry of thermal rearrangement of this system.

Solvolysis of bicyclo[2.2.0]hexenyl *p*-nitrobenzenesulfonate (**2**) in methoxyacetic acid containing 2 equiv of sodium methoxyacetate proceeded in a manner similar to acetolysis of **2** and provided a methoxyacetate (**1c**) (half-life, *ca.* 2.5 hr at 80°).[3] An nmr spectrum ($CDCl_3$) of **1c** was very similar to that of **1a** except for the signals due to the methoxyacetoxy group.[4] The course of acetolysis of **1c** (0.3 *M* solution) was followed by glpc (F & M 5750) analysis (using *cis*-decalin as an internal standard) of no less than ten sealed ampoules immersed in a constant-temperature bath. Compound **1c** underwent two parallel first-order reactions to provide **1a** and **3b**, and a proof for the structure of **3b** is described later (Scheme I). The rate (k_2)

Scheme I



of formation of **1a** was determined to be (3.65 ± 0.14) × 10^{-5} sec^{-1} at 75.5°, (2.66 ± 0.10) × 10^{-4} sec^{-1} at 96.0°, $\Delta H^{\pm}$ = 24 kcal/mol, $\Delta S^{\pm}$ = −10 eu, and k = 9 × 10^{-8} sec^{-1} at 25°.[5] The ratio of k_2/k_3 was 3 to 5 in this temperature range and during the acetolysis formation of **3a** was evident (*vide infra*). Norbornadien-7-yl methoxyacetate (**4**) was prepared for comparison, and the acetolysis of **4** provided the following kinetic parameters (quantitative conversion to the corresponding acetate): k = (1.12 ± 0.03) × 10^{-5} sec^{-1} at 75.5°, (8.70 ± 0.22) × 10^{-5} sec^{-1} at 96.0°, $\Delta H^{\pm}$ = 25 kcal/mol, $\Delta S^{\pm}$ = −10 eu, and k = 2 × 10^{-8} sec^{-1} at 25.0°.[5] Therefore the acetolysis rate of **1c** is estimated to be approximately five times as large as that of **4** at 25°.

(1) (a) J. Meinwald and F. Uno, *J. Am. Chem. Soc.*, **90**, 800 (1968); (b) F. T. Bond and L. Scerbo, *Tetrahedron Letters*, 2789 (1968); (c) K. B. Wiberg and R. W. Ubersax, *ibid.*, 3063 (1968); (d) Y. Hata and H. Tanida, *J. Am. Chem. Soc.*, **91**, 1170 (1969).

(2) S. Masamune, E. N. Cain, R. Vukov, S. Takada, and N. Nakatsuka, *Chem. Commun.*, 243 (1969).

(3) Although we have not attempted exhaustively to prepare **1b** from **1a** a preliminary result indicated that **1b** was extremely unstable. Formation of Δ^3-cyclopentenecarboxaldehyde was evident in several such attempts. Solvolysis of acetate **1a** in acetic acid-d_1 was found to proceed slowly compared to thermolysis of **1a** to provide **3a** (see text) and we were unable to obtain kinetic data for this acetate exchange reaction. Since methoxyacetic acid is a stronger acid (pK_a = 3.52), we expected that acetolysis of **1c** would proceed faster than that of **1a** while rates of thermolysis of the two compounds (**1a** and **1c**) would be in the same order of magnitude.

(4) τ 3.25 (t, 2 H), 5.10 (d, 1 H, J = 6.8 Hz), 5.91 (s, 2 H), 6.52 (s, 3 H), 6.73 (m, 1 H), 7.34 (q, 2 H), and 7.67 (dd, 1 H, J = 6.8, 5.7).

(5) The rate of decrease of **1c** ($k_1 + k_2$) was 4.03 × 10^{-5} at 75.5°, 3.17 × 10^{-4} at 96.0° and k_1 (rate of formation of **3b**) was 3.81 × 10^{-6} sec^{-1} at 75.5°, sec^{-1} 5.07 × 10^{-5} sec^{-1} at 96.0°. Direct determination of k_2 involved the measurement of two glpc peaks (the detector sensitivity to **1a** was different from that to **3a**), thus increasing the magnitude of error. Therefore, the difference between the decrease of **1c** and k_1 was recorded for k_2.