20—30 nm (~40 wt.%) and 40—60 nm (~60 wt.%), respectively. Such a conclusion is in good agreement with the data from microscopic studies.

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References

1. G. Mie, *Ann. Phys.*, 1908, **25**, 377.
2. H. C. van de Hulst, *Light Scattering by Small Particles*, Wiley, New York; Chapman, London, 1957.
3. J. A. Creighton and D. G. Eadon, *J. Chem. Soc., Faraday Trans. 1*, 1991, **87**, 3881.
4. U. Kreibig, *J. Phys. F.*, 1974, **4**, 999.
5. D. C. Skillman and C. R. Berry, *J. Chem. Phys.*, 1968, **48**, 3297.
6. B. G. Ershov, *Izv. Akad. Nauk, Ser. Khim.*, 1994, 25 [*Russ. Chem. Bull.* 1994, **43**, 16 (Engl. Trans.)].
7. M. Gutierrez and A. Henglein, *J. Phys. Chem.*, 1993, **97**, 11368.

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Ring expansion of 4,4-diethyl-1,2-dithiolane in the reaction with butylacetylene. Involvement of anion and radical intermediates

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The action of lithium butyl acetylenide in THF causes 4,4-diethyl-1,2-dithiolane to undergo ring-opening to form 2,2-diethyl-4-thia-5-decyne-1-thiol, which cyclizes to give 2-butyl-6,6-diethyl-5,6-dihydro-1,4-dithiepin by either a homolytic or a nucleophilic mechanism.

Key words: 4,4-diethyl-1,2-dithiolane, ring opening; 2,2-diethyl-4-thia-5-decyne-1-thiol, homolytic or nucleophilic cyclization; 2-butyl-6,6-diethyl-5,6-dihydro-1,4-dithiepin.

The high reactivity of the disulfide bond both in open and cyclic systems in reactions with nucleophilic, electrophilic, and radical reagents is widely used for the synthesis of functionally substituted sulfides.[1] It is well known that 1,2-dithiolanes undergo ring opening to form 3-alkylthio-substituted propanethiols when they are reacted with nucleophilic agents such as either Grignard reagents[2] or organolithium compounds.[3] When acetylenide anions generated from terminal acetylenes react with 1,2-dithiolanes in *tert*-butyl alcohol in the presence of catalytic amounts of Bu^{t}OK, 2-substituted 5,6-dihydro-1,4-dithiepins are formed directly.[4]

In a continuation of studies concerning the application of homolytic methods to the synthesis of sulfur-containing rings and thiacrown-ethers[5] and, in order to develop novel approaches to the construction of sulfur-containing rings, we studied the reaction of a five-membered cyclic disulfide, 4,4-diethyl-1,2-dithiolane (**1**), with butylacetylene. This reaction involves cleavage of the S—S bond and the intermediate formation of 2,2-diethyl-4-thia-5-decyne-1-thiol (**2**) followed by its cyclization with the C=C moiety included in the ring.

Dithiolane **1** readily interacts with lithium butyl acetylenide obtained by the reaction of BuLi with butylacetylene in a THF—hexane mixture (Scheme 1). Ring opening with acetylenide anion rapidly occurs at temperatures below 0 °C to give a solution of 3-alkynylthiopropanethiol lithium salt **4**. Decolorization of the reaction mixture, which was yellow initially, indicates that the reaction is completed.

Acidification of the reaction mixture at this instant makes it possible to obtain thiol **2**, which has not been reported earlier. This fact is confirmed by the ^{1}H NMR spectra recorded just after the treatment of the mixture. In the spectrum of a solution of thiol **2** in $CDCl_3$ there are signals of two nonequivalent CH_2S groups at 2.57 and 2.81 ppm, and one of these signals is a doublet as a result of coupling with the adjacent SH group. We also observed a triplet at 1.25 ppm assigned to the proton bound to sulfur. The attempts to isolate pure thiol **2** failed: in all cases the thiol contained 2-butyl-6,6-diethyl-5,6-dihydro-1,4-dithiepin (**3**) (5—20%), which is the product of intramolecular cyclization (see Scheme 1). When this solution was kept for

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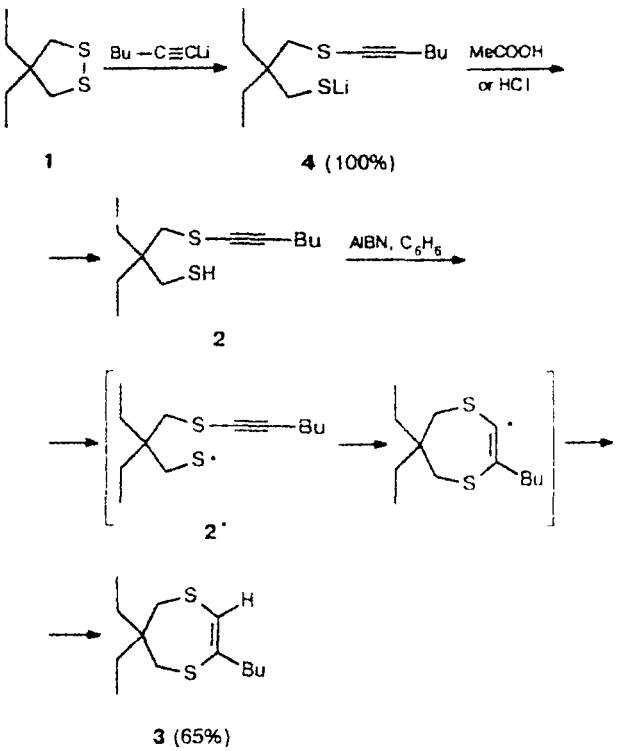
Scheme 1



several days, the content of thiol **2** in it gradually decreased.

This result was not unexpected, because unsaturated thiols are known to be unstable. For example, the reaction of Na_2S with R—C≡C—S$(CH_2)_3$Cl in a water-ethanol mixture leads to a seven-membered dithiepin ring instead of a linear thiol.[6] Earlier we also reported the spontaneous cyclization of a number of homoallylic thiols into five-membered rings in a neutral medium.[7]

In this case, homolysis of the S—H bond in the molecule of thiol **2**, which occurs under the action either of light or of traces of oxygen, leads to products of the intramolecular addition of the thiyl radical **2'** to the triple bond. With a radical initiator, for instance, azobisisobutyronitrile (AIBN), the cyclization in the system studied proceeds more rapidly and is completed in 3 h. The comparatively moderate yield of the cyclization product **3** is probably explained by the participation of radical **2'** in side processes of intermolecular addition to the double and triple carbon—carbon bonds in the reacting system.

It should be noted that in the homolytic addition reactions of α,ω-dithiols to acetylenes, which we studied earlier, the formation of unsaturated thiols was not observed, because they immediately underwent further transformations under the experimental conditions.[5]

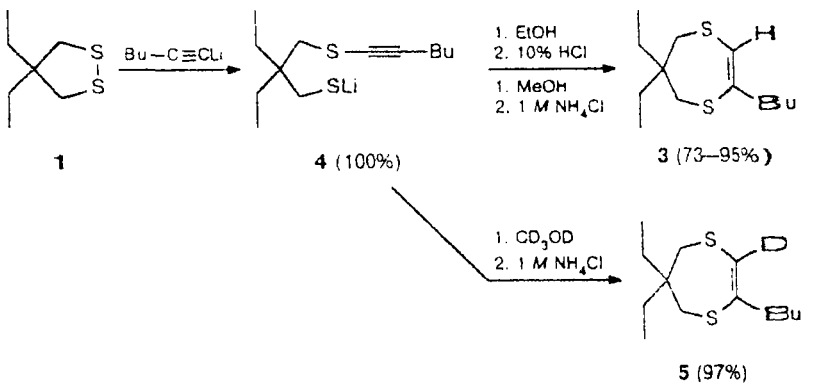
The reaction of dithiolane **1** with butylacetylene, which leads to dithiepin **3**, may also occur *via* thiolate anion cyclization. However, the Li-salt of acetylene thiol **4** proved to be relatively stable in a THF—hexane mixture at room temperature, and it did not undergo cyclization; this is consistent with the well known data.[4] When the solution was boiled, complete conversion of the thiol occured to form a great number of products, among which only traces of dithiepin **3** were found.

Unlike radical cyclization, nucleophilic cyclization, *i.e.*, intramolecular addition of the thiolate anion to the triple bond, occurs more selectively (Scheme 2). The addition of alcohol (ethanol or methanol) allowed us to carry out this reaction at room temperature in 1.5 h and almost quantitatively. After column chromatography the yield of isolated product **3** was 95—97%.

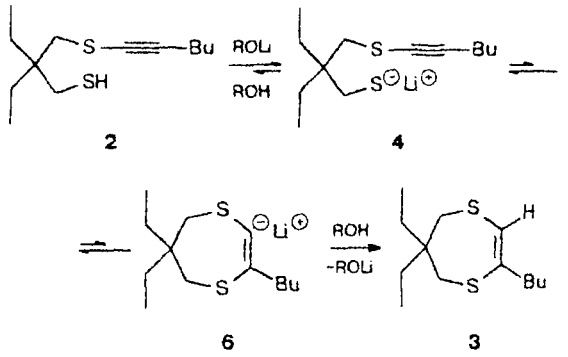
Dithiepin **3** is unstable in an acid medium, which can be seen in the fact that when the reaction mixture is decomposed with dilute HCl its yield is lower than when the decomposition is carried out with a 1 *M* solution of NH_4Cl. When deuterated methanol is used, dithiepin **5**, containing a D atom at the double bond is formed.

The rapid cyclization of **4** in the presence of alcohol and the absence of a reaction a THF—hexane mixture can be explained by the reversibility of the cyclization of lithium thiolate into dithiepin **3**. In an aprotic solvent the equilibrium is shifted to the more stable thiolate anion **4**. The source of protons disturbs the cyclic vinyl anion **6** from the equilibrium state with thiolate **4** (Scheme 3).

Scheme 2



Scheme 3



Experimental

^1H and ^{13}C NMR spectra were recorded on Bruker AM-300-LB, Bruker WM-250 (250 MHz), and Bruker AC-200 (200 MHz) spectrometers in $CDCl_3$. Mass spectra were obtained using a Kratos MS-30 (230 °C, 70 eV) with direct injection of the sample into the ion source. Column chromatography was carried out on L 40/100 Silica gel (hexane as the eluent).

4,4-Diethyl-1,2-dithiolane (1) was synthesized from 2,2-diethylpropane-1,3-diol ditosylate by its reaction with Na_2S_2 in DMF.[8] Yield 58%, b.p. 98—102 °C (10 Torr), n_D^{20} 1.5461. ^1H NMR, δ: 0.91 (t, 6 H, J = 7.6 Hz); 1.58 (q, 4 H, J = 7.6 Hz); 2.89 (s, 4 H).

Reaction of 4,4-diethyl-1,2-dithiolane (1) with lithium butylacetylenide. 1-Hexyne (222 mg, 2.7 mmol) was added to THF (2 mL) under argon and cooled to −80 °C; 2.4 mL of a 0.96 *M* solution of BuLi (2.25 mmol) in hexane was added to the resulting mixture and it was warmed to −20 °C. Dithiolane **1** (217 mg, 0.20 mL, 1.34 mmol) was then added to the resulting mixture; 15 min later (0 °C) the yellow color of the solution of **1** disappeared, and the reaction mixture was then treated using the procedures reported below.

A. The mixture was acidified with 2 mL of 10% HCl, extracted with hexane (2×5 mL), dried with $MgSO_4$, and evaporated. The residue contained 80—95% thiol **2**. ^1H NMR (250 MHz), δ: 0.80 (t, 6 H, 2 CH_3CH_2, J = 7.5 Hz); 0.91 (t, 3 H, CH_3CH_2, J = 7.3 Hz); 1.25 (t, 1 H, SH, J = 8.8 Hz); 1.41 (q, 4 H, 2 CH_2Me, J = 7.5 Hz); 1.4—1.6 (m, 4 H, CH_2CH_2); 2.29 (t, 2 H, $CH_2C{\equiv}CS$, J = 6.7 Hz); 2.57 (d, 2 H, CH_2SH, J = 8.8 Hz); 2.81 (s, 2 H).

B. The reaction mixture was acidified with 2 mL of glacial acetic acid, and benzene (5 mL) and AIBN (15 mg) were then added, and the resulting mixture was refluxed for 3 h, diluted with 15 mL of a saturated $NaHCO_3$ solution, extracted with hexane (2×5 mL), dried over $MgSO_4$, and evaporated. Column chromatography of the residue gave 213 mg of 2-butyl-6,6-diethyl-5,6-dihydro-1,4-dithiepin **3** (213 mg, 65%). Found (%): C, 63.69 and 63.97; H, 9.80 and 9.97; S, 26.20 and 26.37. $C_{13}H_{24}S_2$. Calculated (%): C, 63.87; H, 9.90; S, 26.23. ^1H NMR (250 MHz), δ: 0.79 (t, 6 H, 2 CH_3CH_2, J = 7.5 Hz); 0.90 (t, 3 H, $CH_3(CH_2)_3$, J = 7.3 Hz); 1.2—1.5 (m, 4 H, CH_2CH_2); 1.50 (q, 4 H, 2 CH_2Me, J = 7.5 Hz); 2.11 (t, 2 H, $CH_2C{=}C$, J = 7.5 Hz); 3.07 (br.s, 2 H, CH_2S), 3.09 (br.s, 2 H, CH_2S); 5.67 (s, 1 H, $CH{=}C$). ^{13}C NMR (75.47 MHz), δ: 7.97 (CH_3, Et); 13.94 (CH_3, Bu); 22.03 (CH_2, Bu); 26.39 (CH_2, Et); 31.10 (CH_2, Bu); 39.89 (CH_2, Bu); 40.03 (CH_2, ring); 40.26 (CH_2, ring); 47.18 (C, ring); 112.84 (CH=); 134.70 (C=). MS, m/z (I_{rel} (%)): 244 $[M]^+$ (100), 201 (30), 129 (53), 117 (92), 113 (44), 112 (39), 103 (40), 102 (35), 91 (45), 80 (47).

C. Dry ethanol (2 mL) was added, and the resulting mixture was stirred for 1.5 h at 20 °C, acidified with 2 mL of 10% HCl, extracted with hexane (2×5 mL), dried over $MgSO_4$, and evaporated. Dithiepin **3** (240 mg, 73%) was isolated from the residue by chromatography. The spectral data are similar to those presented above.

D. Dry methanol (2 mL) was added, and the resulting mixture was stirred for 1.5 h at 20 °C. Then 2.5 mL of a 1 *M* solution of NH_4Cl was added and the mixture was extracted with hexane, dried over $MgSO_4$, and evaporated. Dithiepin **3** (311 mg, 95%) was isolated from the residue by chromatography. The spectral data are similar to those presented above.

E. 3-Deuterodithiepin **5** (319 mg, 97%) was synthesized similarly using CD_3OD (2 mL). ^1H NMR (250 MHz), δ: 0.79 (t, 6 H, 2 CH_3CH_2, J = 7.5 Hz); 0.90 (t, 3 H, $CH_3(CH_2)_3$, J = 7.3 Hz); 1.2—1.5 (m, 4 H, CH_2CH_2); 1.50 (q, 4 H, 2 CH_2Me, J = 7.5 Hz); 2.11 (t, 2 H, $CH_2C{=}C$, J = 7.5 Hz); 3.07 (br.s, 2 H, CH_2S); 3.09 (br.s, 2 H, CH_2S). ^{13}C NMR (50.32 MHz), δ: 8.00 (CH_3, Et); 13.94 (CH_3, Bu); 22.04 (CH_2, Bu); 26.40 (CH_2, Et); 31.09 (CH_2, Bu); 39.84 (CH_2, Bu); 40.01 (CH_2, ring); 40.26 (CH_2, ring); 47.20 (C, ring); 112.58 (CD=, $J_{^{13}C-^2D}$ = 25.8 Hz); 134.70 (C=). MS, m/z (I_{rel} (%)): 245 $[M]^+$ (100), 202 (33), 129 (34), 119 (38), 118 (36), 113 (35), 112 (30), 104 (32), 97 (33), 82 (34).

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References

1. I. V. Koval', *Usp. Khim.*, 1994, **63**, 776 [*Russ. Chem. Rev.*, 1994, **63** (Engl. Transl.)].
2. (a) M. Tazaki, S. Nagahama, and M. Takagi, *Chem. Lett.*, 1988, 1339; (b) M. Tazaki, H. Tanabe, S. Nagahama, and M. Takagi, *Sulfur Lett.*, 1993, **16**, 237.
3. M. Tazaki, H. Tanabe, T. Hieda, S. Nagahama, K. Inoue, and M. Takagi, *Phosphorus, Sulfur, Silicon, Relat. Elem.*, 1994, **88**, 189.
4. M. Tazaki, M. Kumakura, S. Nagahama, and M. Takagi, *J. Chem. Soc., Chem. Commun.*, 1995, 1763.
5. (a) D. V. Demchuk, A. I. Lutsenko, E. I. Troyansky, and G. I. Nikishin, *Izv. Akad. Nauk SSSR. Ser. Khim.*, 1990, 2801 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1990, **39**, 2542 (Engl. Trans.)]; (b) E. I. Troyansky, M. I. Lazareva, D. V. Demchuk, V. V. Samoshin, Yu. A. Strelenko, and G. I. Nikishin, *Synlett*, 1992, 233; (c) D. V. Demchuk, M. I. Lazareva, S. V. Lindeman, V. N. Khrustalyov, Yu. T. Struchkov, R. F. Ismagilov, E. I. Troyansky, and G. I. Nikishin, *Synthesis*, 1995, 307.
6. R. S. Sukhai, R. De Jong, H. D. Verkruijsse, and L. Brandsma, *Recl.: J. R. Neth. Chem. Soc.*, 1981, **100**, 368; *Chem. Abstrs.*, 1982, 96, 104204.
7. G. I. Nikishin, V. I. Zheludeva, L. I. Lavrinovich, D. V. Demchuk, E. I. Troyansky, and Yu. N. Bubnov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1989, 2155 [*Bull. Acad. Sci. USSR. Div. Chem. Sci.*, 1989, **38**, 1985 (Engl. Trans.)].
8. E. L. Eliel, V. S. Rao, S. Smith, and R. O. Hutchins, *J. Org. Chem.*, 1975, **40**, 524.

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