(±)-2,3,5-Trichloro-4,4-dimethoxycyclopent-2-en-1-one (2), m.p. 52—54 °C. IR (ν/cm^{-1}): 1600, 1750. ^{1}H NMR ($CDCl_3$), δ: 3.47 (s, 3 H, OCH_3); 3.49 (s, 3 H, OCH_3); 4.55 (s, 1 H, 5-H). ^{13}C NMR ($CDCl_3$), δ: 52.03 and 52.09 (OCH_3), 62.19 (C-5); 100.60 (C-4); 133.82 (C-2), 157.65 (C-3); 186.14 (C-1). MS (*m/z*): 244 $[M]^+$, 213 $[M-OCH_3]$, 209 $[M-Cl]$. Found (%): C, 34.13; H, 2.83; Cl, 43.45. $C_7H_7Cl_3O_3$. Calculated (%): C, 34.22; H, 2.85; Cl, 43.38.

(±)-2,2-Dimethyl-3-methylenebicyclo[2.2.1]heptane (3), m.p. 50—51 °C. ^{1}H NMR ($CDCl_3$) δ: 1.00 (s, 3 H, CH_3), 1.06 (s, 3 H, CH_3); 1.88 (m, 1 H, 4-H); 2.66 (m, 1 H, 1-H); 4.48 (s, 1 H, $C=CH_2$). ^{13}C NMR ($CDCl_3$), δ: 23.85 (C-6); 25.87 (CH_3); 28.95 (C-5); 29.45 (CH_3); 37.47 (C-7); 41.88 (C-2); 46.99 (C-4); 48.21 (C-1); 99.06 (C-3); 166.43 ($=CH_2$). The spectral characteristics of compound **3** coincided with those reported in the literature.[2,3]

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Competitive reactivity of vinylchalcogenyl radicals in their reactions with acetylene

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The reactivities of vinylthiyl and vinylselenyl radicals generated by high temperature gas-phase reactions of acetylene with diethyl disulfide and diethyl selenide, respectively, were compared. The co-pyrolysis of a mixture of these reagents at 410—510 °C results in a mixture of thiophene and selenophene. The vinylselenyl radical is more reactive; in addition, it appears to stabilize vinylthiyl radicals. Owing to this, co-thermolysis of diethyl disulfide, diethylselenide, and acetylene at 510 °C allows one to obtain simultaneously thiophene and selenophene in 91.0 and 92.5 % yields, respectively.

Key words: acetylene, gas-phase reactions, thiyl and selenyl radicals, thiophene, selenophene.

The thermolysis of the lowest dialkyl disulfides results in the generation of vinylthiyl radicals, which react with acetylene to give thiophene. The yield of the latter at 420—470 °C is 47—62 %.[1,2] Vinylselenyl radicals are efficiently generated in the thermolysis of dimethyl selenide. Their reactions with acetylene at 420—470 °C give selenophene in up to 90 % yields.[3] In a continuation of a study of the reactivity of thermally generated vinyl chalcogenyl radicals, we studied, under comparable conditions, the co-thermolysis of acetylene with diethyl disulfide (**1**), diethyl selenide (**2**), and their mixture (Table 1). The structure of the alkyl chain in these chalcogenides implies that the corresponding vinyl chalcogenyl radicals should be generated more efficiently from them than from other dialkyl chalcogenides.

The reaction of acetylene with diethyl disulfide at 480—500 °C results in thiophene in 45—50 % yield. This also gives side products, *i.e.*, thienothiophenes and aromatic hydrocarbons. Diethyl selenide reacts selectively with acetylene at 460 °C to give selenophene in an almost quantitative yield. The co-thermolysis of acetylene with a mixture of diethyl disulfide and diethyl selenide occurs in a somewhat different way. The main reaction products include sulfur disulfide, thiophene, and selenophene. Their yields and ratio depend considerably on the reaction temperature. At 410 °C and with incomplete conversion of diethyl disulfide, carbon disulfide is the main reaction product (Table 1).[1] Thiophene and selenophene are formed in nearly equal yields. The difference in the reactivities of the vinylthiyl and

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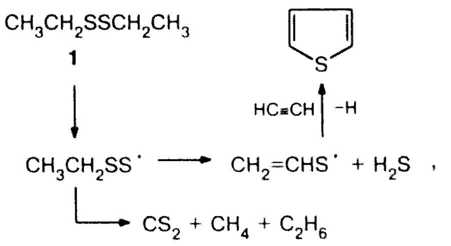
Table 1. Reactions of $CH_3CH_2SSCH_2CH_3$ (**1**) and $CH_3CH_2SeCH_2CH_3$ (**2**) with acetylene

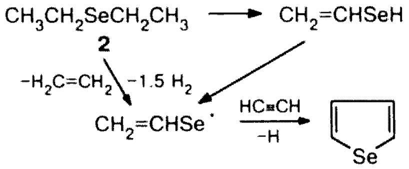
Reagent	Reaction temperature/°C	Reagent/acetylene ratio	Yield (% with respect to the initial reagent)		
			CS_2	Thiophene	Selenophene
1	480	1:2	—	45.0[a]	—
1	500	1:2	—	59.0[a]	—
2	480	1:2	—	—	98.5
1+2	410	1:1:4	59.8[b]	35.8	36.6
1+2	440	1:1:4	17.1	53.4	78.3
1+2	470	1:1:4	9.3	84.3	83.6
1+2	500—510	1:1:4	2.6	91.0	92.8

[a] Mixtures of isomeric thienothiophenes (8 and 10 %) and benzene and toluene (up to 2 %) are simultaneously formed.
[b] The degree conversion of **1** is 90 %.

vinylselenyl radicals manifests itself at 440 °C, *i.e.*, the yield of thiophene increases by a factor of 1.5, while that of selenophene doubles. Simultaneously, the yield of carbon disulfide decreases abruptly:

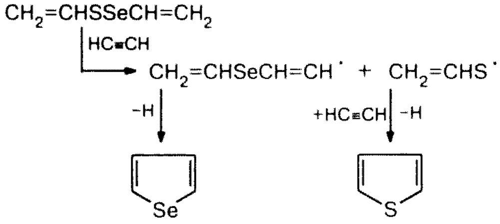


(1)



(2)

At higher temperatures (470—510 °C), reactions (1) and (2) result in selective formation of thiophene and selenophene in up to 90—92 % yields (in this case, the yield of carbon disulfide decreases to 2 %). The results obtained indicate that the vinyl selenyl radicals have a higher affinity for acetylene than the vinyl thiyl radicals. At 410 °C, acetylene is yet insufficiently activated for the effective trapping of vinyl chalcogenyl radicals, and hence the yield of thiophene and selenophene is low. Under these conditions, diethyl disulfide decomposes thermally to give mostly carbon disulfide.[1] In the case of moderate activation of acetylene (440 °C), the vinylselenyl radical reacts with acetylene more rapidly than the vinylthiyl radical. At 470—510 °C, when the activity of acetylene is high, the co-thermolysis of a mixture of diethylchalcogenides with acetylene results in a yield of selenophene that is close to its yield from the co-thermolysis of acetylene with diethylselenide. However, the yield of thiophene appears to be unusually high (91 % as compared with 50 % obtained from diethyl disulfide alone). In this case, the mutual influence of the reagents during their co-reaction with acetylene according to reactions (1) and (2) can be clearly seen. This influence may result from the fact that vinylthiyl and vinylselenyl radicals can undergo dimerization, as previously mentioned for similar alkylselenyl radicals.[3,4] The formation of such a dimer as CH=CHSSeCH=CH can, first, stabilize the vinylthiyl radicals by impeding their thermal decomposition and, second, favor their direct generation in the reaction of the dimer with acetylene through attack on the triple bond by the selenium atom:



(3)

The formation of the dimer and its reactions with acetylene (3) probably occur at temperatures above 450 °C. This may result in the high selectivity of the reaction of a mixture of diethyl disulfide and diethylselenide with acetylene with respect to both selenophene and thiophene when the initial reagents are completely consumed. Thus, the stabilization of thiyl radicals by selenyl radicals opens new prospects for synthesizing heterocyclic compounds of thiophene, selenophene and other series and for predicting selective methods for their synthesis.

Experimental

The liquid reaction products were analyzed by GLC on a LKhM-8MD-2 chromatograph (2 m ×3 mm column, DS-550, 5 % as the liquid phase on Chromaton N-AW-HMDS, with helium as the carrier gas). The column temperature was programmed linearly from 35 to 240 °C at a rate of 12 deg min^{-1}. GLC-MS analysis was carried out on an LKB-2091 instrument (capillary column, SE-30 phase, linear programming of column temperature from 135 to 240 °C at a rate of 8 deg min^{-1}), ionization energy 70 eV.

The reactions of diethyl disulfide, diethylselenide, and their mixtures with acetylene were carried out in a quartz hollow tubular reactor with a 19 ×20 mm heating zone, which was placed into an electric oven. The starting sulfides were fed into the reactor in a stream of acetylene by an automatic syringe dispenser at a rate of 3.2 mL per hour. Acetylene was prepared in a Kipp apparatus and fed into the reactor at a rate corresponding to the required reagent ratio. The temperature in the reactor was monitored by a thermocouple installed in the middle of the heating zone outside of the reactor and connected to an automatic regulator. The reaction mixture was condensed into cooled traps at the reactor outlet. Thiophene and selenophene were readily isolated by distillation of the reaction mixtures. The structures of the compounds were confirmed by GLC and GLC-MS spectrometric data for the individual heterocycles, as well as for reaction mixtures. The reaction conditions and yields of the main reaction products are given in Table 1.

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Synthesis of 1,7-bis(carboxyalkylcarbamoyl)-*m*-carboranes as precursors of possible water-soluble preparations for boron-neutron-capture treatment of cancer

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By the interaction of the corresponding amino acids with the dichloride of *m*-carboranedicarboxylic acid, 1,7-bis-(carboxyalkylcarbamoyl)-*m*-carboranes were prepared are characterized for the first time. These compounds are of interest as intermediates for the synthesis of water-soluble preparations for the boron-neutron-capture therapy of cancer.

Key words: bis(carboxyalkylcarbamoyl)-*m*-carboranes, *m*-carboranedicarboxylic acid, oligosalts.

One of the main challenges in the neutron-capture therapy of cancer is the development of water-soluble preparations that can act as boron carriers and are capable of being predominantly accumulated in the tissue of a tumor.

In recent years, studies aimed at the synthesis of boron-rich carborane-containing compounds have attracted considerable interest.[1–6] However, the compounds described in the literature are often poorly soluble in water and are obtained using complicated multistage procedures. Previously, a simple and accessible method for the preparation of oligosalts of *m*-carboranedicarboxylic acid, readily soluble in water, was proposed[7] and it was shown that these compounds can be used in the boron-neutron-capture therapy of cancer.

It would be expected that the introduction of organic and amide groups into these oligosalts would improve their biological properties.[8]

For this purpose, we synthesized the previously unknown 1,7-bis(carboxyalkylcarbamoyl)-*m*-carboranes (**1**) as intermediate compounds to be used for the preparation of water-soluble oligosalts.

These compounds were obtained by acylation of various amino acids with the dichloride of *m*-carborane-

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[†] Deceased.

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