SYNTHESIS OF CYCLIC SULFIDES.

VIII.* SYNTHESIS OF 4-ALKYLTHIACYCLOHEXANES

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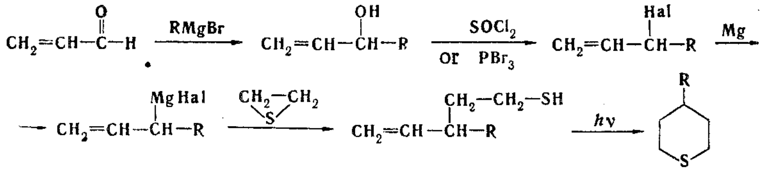
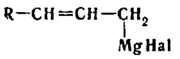
A general scheme is proposed for the synthesis of 4-alkylthiacyclohexanes by reaction of 1-alken-3-ylmagnesium halides with ethylene episulfide and subsequent cyclization of the resulting 3-alkylpent-4-ene-1-thiols under the influence of UV irradiation. 4-Amyl- and 4-octylthiacyclohexanes, together with 2-methyl-3-octylthiacyclopentane, were obtained, respectively, from 1-octen-3-ylmagnesium bromide, 1-undecen-3-ylmagnesium chloride, and ethylene episulfide.

A general scheme for the synthesis of 4-alkylthiacyclohexanes was described in [2]; this scheme has eight steps, and the desired product is obtained in 13.8% overall yield. We propose the following scheme for the synthesis of 4-alkylthiacyclohexanes in 20-28% overall yield:

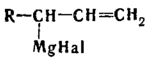


4-Amyl- and 4-octylthiacyclohexanes were obtained via the proposed scheme. Mixtures of isomeric 3-halo-1-alkenes and 1-halo-2-alkenes with predominance of the latter are obtained in the reaction of 1-alken-3-ols with $SOCl_2$ or PBr_3 in the presence of pyridine. The Grignard reagent obtained from this mixture forms an equilibrium mixture (Ia,b), which reacts with ethylene episulfide to give 3-alkyl-4-pentene-1-thiol [3]; this was confirmed by the structures of the thiacyclanes formed in the cyclization of these mercaptans under the influence of UV irradiation.



$R{-}CH{=}CH{-}\underset{\displaystyle MgHal}{CH_2}$

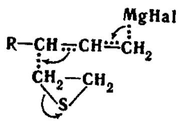
Ia



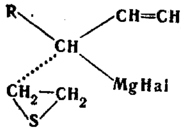
$R{-}\underset{\displaystyle MgHal}{CH}{-}CH{=}CH_2$

Ib

3-Alkyl-4-pentene-1-thiols are formed with accompanying S_E2' rearrangement from the predominant primary isomer Ia rather than through direct conversion from secondary isomer Ib, since in the case of an S_E2 mechanism strong repulsion between the entering electrophilic reagent and the leaving metal-containing group should have occurred in the transition state [4, 5]. This repulsion is absent in the transition state in the case of the S_E2' mechanism, so that the electrophile and the metal-containing group are attached to different carbon atoms.



S_E2'



S_E2

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*See [1] for communication VII.

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The reaction of octenylmagnesium bromide with ethylene episulfide gave a mixture containing, according to the results of gas–liquid chromatography (GLC), 4-amylthiacyclohexane (53.8%), 2-methyl-3-amylthiacyclopentane (2.8%), 3,4-diamyl-1,5-hexadiene (or 3-amyl-1,5-undecadiene) (36.3%), and 6,10-hexadecadiene.*

The formation of unsaturated hydrocarbons in the reaction of bromooctene with magnesium is explained by the high lability of the bromine atoms in it; this lability leads to dimerization of the radicals [6]. The latter reaction leads to a decrease in the yields of thiacyclanes, and chloroalkenes are therefore more suitable in the proposed scheme for their synthesis.

The cyclization of 3-amyl-4-pentene-1-thiol by UV irradiation is complete in 6-8 h with the primary formation of a thiacyclane with a six-membered ring. The cyclization of 3-octyl-4-pentene-1-thiol proceeds in 40-50 h, during which a considerable amount of 2-methyl-3-octylthiacyclopentane (26%) is formed along with 4-octylthiacyclohexane (74%). Thus an increase in the size of the hydrocarbon group in 3-alkyl-4-pentene-1-thiols during UV irradiation not only promotes the formation of thiacyclanes with a five-membered ring [7] but also leads to a considerable decrease in the rate of cyclization.

Chromatographically pure 4-alkylthiacyclohexanes and 3,4-diamyl-1,5-hexadiene (or 3-amyl-1,5-undecadiene) were isolated by rectification, whereas 95% pure 2-methyl-3-octylthiacyclopentane was isolated by this means. Complexes with mercuric chloride and methiodides, sulfones, and sulfoxides were obtained from the thiacyclanes and characterized.

The structures of the thiacyclanes were confirmed by the IR and mass spectra. The IR spectra of 4-amyl- and 4-octylthiacyclohexanes and 2-methyl-3-octylthiacyclopentane contain, respectively, absorption maxima characteristic for the skeletal vibrations of cyclic sulfides (1275, 1280, and 1260 cm^{-1}). The intensity of the band at 1380 cm^{-1} (CH_3 group) in the spectrum of 4-octylthiacyclohexane is half the intensity of the band in the spectrum of 2-methyl-3-octylthiacyclopentane. The IR spectrum of 3,4-diamyl-1,5-hexadiene (or 3-amyl-1,5-undecadiene) contains bands characteristic for a vinyl group (920, 970, 1640, and 3085 cm^{-1}). The intensities of the peaks of the $C_5H_9S^+$ and $C_6H_{11}S^+$ fragment ions in the mass spectra of 4-amyl- and 4-octylthiacyclohexanes are, respectively, 26 and 100% of the maximum peak, in contrast to 2-amyl- and 3-amylthiacyclohexanes, in the mass spectra of which the intensities of the peaks of the $C_6H_{11}S^+$ fragment ion are 10 and 8%.

EXPERIMENTAL

The IR spectra of liquid films of the compounds were recorded with a UR-20 spectrometer with NaCl and LiF prisms. The mass spectra were recorded with an MKh-1303 spectrometer at an ionizing-ion energy of 70 eV, an emission current of 1.5 mA, and an ionization-chamber temperature of 150°C. Analysis by GLC was carried out with a UKh-2 chromatograph with a column (L = 4 m, d = 4 mm) filled with 10% E-301 on Chromosorb W with helium as the carrier gas (V = 50 ml/min). The haloalkenes were removed at 124°C, and the thiacyclanes were removed at 224°C.

1-Octen-3-ol, with bp 87-89°C (60 mm), n_D^{20} 1.4370, and d_4^{20} 0.8324 [bp 88-90°C (20 mm), n_D^{30} 1.4329, and d_4^{20} 0.8325 [9]], was obtained in 63% yield by the method in [8]. 1-Undecen-3-ol, with bp 169°C (5 mm), n_D^{20} 1.4445, and d_4^{20} 0.8376, was obtained in 54% yield by the method used to prepare 1-octen-3-ol. IR spectrum (thin layer): 930, 1000, 3090 ($-CH=CH_2$), and 3360 cm^{-1} (O-H). Found, %: C 77.3; H 12.9. MR_D 53.95. $C_{11}H_{22}O$. Calculated, %: C 77.6; H 12.9. MR_D 54.06. Bromooctene, with bp 88-89°C (10 mm), n_D^{20} 1.4745, and d_4^{20} 1.1299, was obtained in 84% yield by the method in [10]; according to GLC data, the product consisted of 3-bromo-1-octene (23%) and 1-bromo-2-octene (77%) [bp 73-77°C (14 mm) [10]]. Chloroundecene, with bp 169-171° (4 mm), n_D^{20} 1.4508, and d_4^{20} 0.8738, was obtained in 90% yield by the method in [11]; according to the GLC data, the product consisted of 3-chloro-1-undecene (15%) and 1-chloro-2-undecene (85%). Found, %: C 69.8; H 10.9; Cl 19.0. MR_D 58.07. $C_{11}H_{21}Cl$. Calculated, %: C 70.0; H 11.1; Cl 18.8. MR_D 57.40. Ethylene episulfide was obtained by the method in [12].

4-Amylthiacyclohexane. Freshly distilled ethylene episulfide [10 g (0.17 mole)] was added in the course of 40 min at −10°C to octenylmagnesium bromide, obtained from 20 g (0.83 g-atom) of magnesium and 40 g (0.21 mole) of bromooctene in 50 ml of absolute ether,

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*The structure was not established.

and the mixture was stirred at room temperature for 1 h, after which it was refluxed for 4 h and allowed to stand overnight. It was then decomposed in a stream of nitrogen with a saturated solution of ammonium chloride. The organic layer was separated, and the aqueous layer was extracted with ether (two 100-ml portions). The extract was combined with the organic layer, the ether was removed by distillation, and the residue was vacuum distilled. The distillate was diluted with freshly distilled ether and illuminated with a PRK-2 lamp until it gave a negative test for mercaptan [13]. Removal of the ether by distillation and vacuum distillation of the residue gave 26.5 g of a mixture, which, according to the GLC data, consisted of 2-methyl-3-amylthiacyclopentane (2.8%), 4-amylthiacyclohexane (53.8%), 3,4-diamyl-1,5-hexadiene or 3-amyl-1,5-undecadiene (36.3%), and 6,10-hexadecadiene (7.1%). The yield of 4-amylthiacyclohexane was 47% of the theoretical value (based on ethylene episulfide). Rectification of this mixture yielded chromatographically pure 4-amylthiacyclohexane with bp 154°C (110 mm), n_D^{20} 1.4850, d_4^{20} 0.9167, and M 172 [bp 101°C (12 mm), n_D^{20} 1.4862, and d_4^{20} 0.9239 [2]]. The complex with mercuric chloride had mp 107-108°C. Found, %: S 7.2. $C_{10}H_{20}S \cdot HgCl_2$. Calculated, %: S 7.2. The sulfone had mp 84-85°C. Found, %: C 58.8; H 9.9; S 15.6. $C_{10}H_{20}O_2S$. Calculated, %: C 58.8; H 9.8; S 15.7. The methiodide had mp 127-128°C. Found, %: I 40.7. Calculated for $C_{10}H_{20}S \cdot CH_3I$: I 40.4%. The sulfoxide had n_D^{20} 1.4920 and d_4^{20} 1.0045. Found, %: C 63.5; H 10.7; S 16.5. $C_{10}H_{20}OS$. Calculated, %: C 63.8; H 10.6; S 17.0.

3,4-Dimethyl-1,5-hexadiene. This compound had bp 203-204°C (20 mm), n_D^{20} 1.4500, and d_4^{20} 0.7913. Found, %: C 86.3; H 13.8. MR_D 75.42. $C_{16}H_{30}$. Calculated, %: C 86.5; H 13.5. MR_D 75.06.

4-Octylthiacyclohexane. This compound was obtained from 89.5 g (0.475 mole) of chloroundecene and 28.5 g (0.475 mole) of ethylene episulfide by a method similar to the method described for 4-amylthiacyclohexane. Cyclization of the resulting unsaturated mercaptan by UV irradiation gave 60 g (59%) of a mixture consisting, according to the GLC data, of 2-methyl-3-octylthiacyclopentane (26%) and 4-octylthiacyclohexane (74%). The latter was obtained in 44% yield. Rectification with a column with an efficiency of 16 theoretical plates yielded chromatographically pure 4-octylthiacyclohexane with bp 194°C (50 mm), n_D^{20} 1.4830, and d_4^{20} 0.8983. Found, %: C 73.0; H 12.1; S 15.1. M 214. MR_D 68.08. $C_{13}H_{26}S$. Calculated, %: C 72.9; H 12.2; S 15.0. M 214. MR_D 67.95. The complex with mercuric chloride had mp 106-107°C. Found, %: S 6.6. Calculated for $C_{13}H_{26}S \cdot HgCl_2$: S 6.6%. The sulfone had mp 89-90°C. Found, %: C 63.7; H 10.7; S 12.9. $C_{13}H_{26}O_2S$. Calculated, %: C 63.4; H 10.6; S 13.0. The methiodide had mp 127-129°C. Found, %: I 39.9. Calculated for $C_{13}H_{26}S \cdot CH_3I$: I 39.9. The sulfoxide had mp 79-80°C. Found, %: C 68.0; H 11.2; S 13.5. $C_{13}H_{26}OS$. Calculated, %: C 67.8; H 11.3; S 13.9.

2-Methyl-3-octylthiacyclopentane.* This compound had bp 190°C (40 mm), n_D^{20} 1.4787, and d_4^{20} 0.8978. Found, %: C 73.2; H 12.3; S 14.7. MR_D 67.55. $C_{13}H_{26}S$. Calculated, %: C 72.9; H 13.2; S 15.0. MR_D 67.95. The complex with mercuric chloride had mp 103-104°C (dec.). Found, %: S 6.4. Calculated for $C_{13}H_{26}S \cdot HgCl_2$: S 6.6%. The sulfone had n_D^{20} 1.4772 and d_4^{20} 1.0038. Found, %: C 63.7; H 10.4; S 12.9. MR_D 69.27. $C_{13}H_{26}O_2S$. Calculated, %: C 63.4; H 10.6; S 13.0. MR_D 68.90. The methiodide had mp 127-128°C. Found, %: I 39.4. Calculated for $C_{13}H_{26}S \cdot CH_3I$: I 39.9%. The sulfoxide had n_D^{20} 1.4875 and d_4^{20} 0.9573. Found, %: C 67.9; H 11.1; S 13.8. MR_D 69.17. $C_{13}H_{26}OS$. Calculated, %: C 67.8; H 11.3; S 13.9. MR_D 69.10.

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*95% pure according to GLC data.

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REGIOSELECTIVITY OF THE ALLYLATION OF BENZOTHIOPHENE

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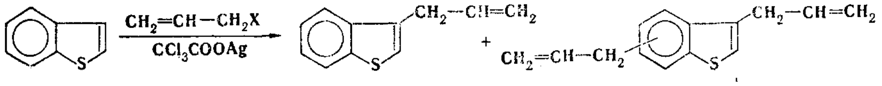
The reaction of benzothiophene with allyl halides in the presence of silver trichloroacetate in chlorine-containing hydrocarbons was investigated. It was established by gas–liquid chromatography and ^{13}C NMR and mass spectrometry that 3-allylbenzothiophene and diallylbenzothiophene are formed in this case. The ^{13}C NMR spectra were interpreted on the basis of an additive scheme with the utilization of benzothiophene, thiophene, and 2- and 3-allylthiophenes as models.

The known reactions involving the alkylation of benzothiophene have been carried out under acid catalysis conditions [1-3]. However, the possibility of migration of the alkyl group in this case [4] leads to a mixture of 2- and 3-alkylbenzothiophenes, i.e., it makes the reaction nonselective. We therefore set up experiments under conditions that exclude positional isomerization. These conditions are realized in the allylation of furan or benzofuran by allyl halides in the presence of silver trichloroacetate in chlorine-containing hydrocarbons [5, 6].

It was found that the allylation of benzothiophene with allyl iodide in the presence of silver trichloroacetate proceeds, according to the results of gas–liquid chromatography (GLC) and ^{13}C NMR spectroscopic and mass spectrometric data, to give only 3-allylbenzothiophene (I) when the experiment is carried out for less than 5 min (Table 1). This fact is in good agreement with the literature data on electrophilic substitution in benzothiophene, which takes place primarily in the 3 position. An increase in the reaction time leads to the appearance in the reaction mixture of another compound which, according to mass spectrometric data, has a molecular weight of 214, i.e., diallylbenzothiophene (II), in which the second allyl group is evidently located in the benzene ring. Replacement of allyl iodide by the corresponding bromide promotes an increase in the selectivity of the allylation of benzothiophene (Table 1).



I

II

X = Br, I

The assignment of the resonance signals in the ^{13}C NMR spectrum of I was made with the use of the additive principles of ^{13}C chemical shifts. We selected thiophene, 2-allylthiophene, and 3-allylthiophene as models for the construction of the additive scheme. The carbon magnetic resonance spectra of these compounds were analyzed on the basis of the literature data (for thiophene [7] and from the $^{13}C{-}^{1}H$ spin–spin coupling constants for alkylthiophenes [8]), the ^{13}C monoresonance spectra of 2-allyl- and 3-allylthiophenes, and by the use of 2-D- and 3-D-benzothiophenes as models. We carried out the assignment of the resonance signals of the 4-C and 7-C atoms of the six-membered ring of benzothiophene by the "fingerprint" method [9] and obtained results that are in agreement with the recently published results [10] on the basis of an analysis of a series of alkylbenzothiophenes (Table 2).

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