A short synthesis of some monoterpenoids from the adduct of myrcene with benzenesulfinyl chloride

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The title adduct was converted into 1,2-epoxymyrcene; its cationic 5-*exo*-cyclization gave a (±)-hop ether having the iridane-type skeleton. Effective syntheses of a furanoterpene perillene and some functionalized cyclopentanoid monoterpenes regioisomeric to iridoids were elaborated using sulfur-containing geraniol derivatives easily accessible from the same adduct in a synthetic sequence including the Pummerer reaction and anionic cyclization.

Key words: myrcene, geraniol, perillene, hop ether, iridoids, cyclopentanoid monoterpenes, sulfonium salts, pummerer reaction.

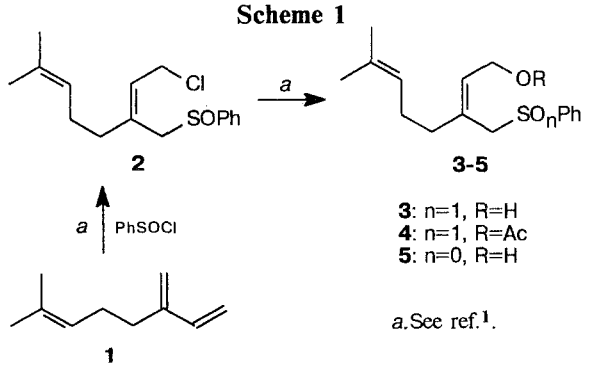
We have reported previously[1] that high-pressure Diels-Alder heteroaddition of benzenesulfinyl chloride to β-myrcene (**1**) affords *Z*-chlorosulfoxide (**2**) regiospecifically; the latter was easily transformed into sulfur-containing geraniol derivatives (**3**)—(**5**) (Scheme 1). In the present paper the use of these functionalized dienes for the synthesis of natural monoterpenoids and related compounds is described (Scheme 1).

The furanoterpene perillene (**7**) chosen to serve as an illustration is a component of communication secretions of some insects,[2] and is also found in certain essential oils.[3] We propose a facile synthesis of **7** (Scheme 2) which is based on the smooth Pummerer-like conversion[4] of the phenylsulfinylmethyl group into the aldehyde function together with heterocyclization[5] of hydroxyaldehydes of the type **6** to yield **7**. As expected, a low-temperature version of the silyl-type[4] Pummerer reaction afforded the furan **7** in more than 50% yield from **3** with characteristics identical in all respects to those previously reported.[6]

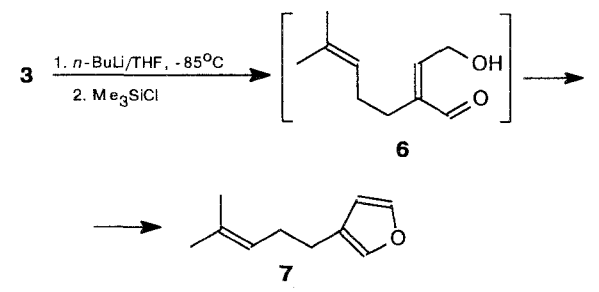
Prerequisites for further synthetic application of adduct **2** were its dehydrochlorination into 1,3-dienesulfoxides **8** (*cf.* similar reactions of isoprene derivatives[7]) and transformation of **8** into individual phenylthiomonoterpenol (**11**) (Scheme 3). Alkaline treatment of **2** in a biphasic system smoothly gave a mixture of (*E*/*Z*)-sulfoxides **8** (Scheme 3). The ratio *E*-**8**/*Z*-**8** ~ 4:1 was determined from the relative integral intensity (RII) of well-separated olefinic protons HCS (δ 6.2 and 6.1, ^{1}H NMR) and proved by chromatographic separation of the mixture on silica gel. As shown earlier for related systems,[8] the $HC{=}CH_2$ signal in the *cis*-isomer is shifted downfield *vs.* its *trans*-counterpart; the signals of (*E*/*Z*)-**8** were at δ 7.2 (minor) and 6.3 (major), respectively.

The second transformation is based on an observation of the course of an attempted Michael addition of PhSNa to an activated diol **8** where vicinal phenylthioalcohol **11** was obtained in a good yield when the components refluxed in methanol. This result can be explained as the initial formation of an ambident anion **9** which is then transformed into a thermodynamically stable (*cf.*[9]) allylic sulfoxide **10**, and [2,3]-sigmatropic rearrangement of the latter[10] into the alcohol **11**. The above considerations were in agreement with the labelling experiments. When the reaction was carried out in MeOD, RII of $H_2C{=}C$ protons (δ 5.2) and HCO (δ 4.2) in **11** decreased due to partial exchange of the corresponding protons with deuterons. Incorporation of D into the product was proved by MS.

Scheme 1



Scheme 2



†Deceased Nov., 1, 1992.

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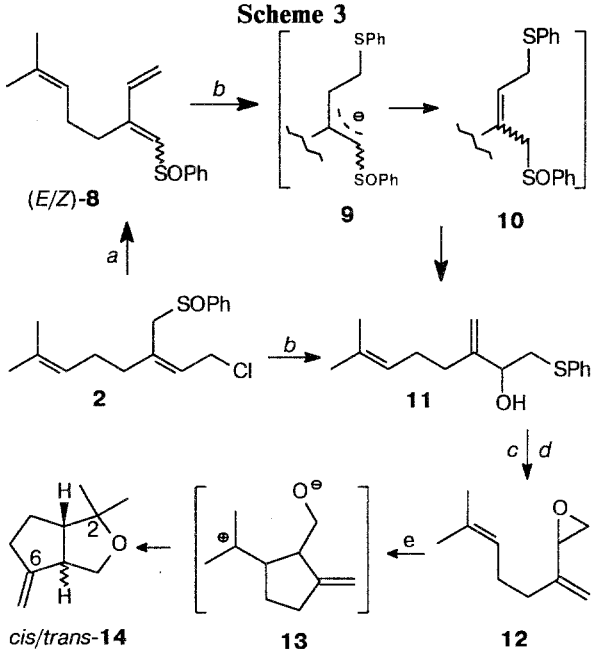
Scheme 3



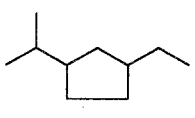
a. $NaOH/H_2O/MeOH/Et_2O$, 25°C; *b*. PhSNa/MeOH, reflux; *c*. $Me_3O^+BF^-/CH_2Cl_2$, −10→25°C; *d*. 5% NaOH, 0→25°C; *e*. $F_3B \cdot OEt_2/CH_2Cl_2$, −78°C.

The proposed mechanism of the **8**→**11** transformation allows to realize a direct synthesis of **11** from **2** without the intermediacy of labile 1,3-dienes. Indeed, treatment of **2** with 2.5 mol.-eq. of PhSNa, which acts initially as a dehydrochlorination agent, in MeOH gave **11** in 60% yield (Scheme 3).

The thioalcohol **11** may be useful as a building block in the syntheses of linear and cyclic terpenes. For example,[11] myrcene oxide **12** was prepared in more than 50% yield by treatment of **11** with Meyerwein's reagent followed by alkaline cyclization of the intermediate sulfonium salt (one-pot procedure) obtained. The new epoxide **12** is rather unstable and cannot be prepared by direct epoxydation[12] of myrcene **1**; its structure was supported by spectral data. This effective, formally two-step synthesis of **12** from the chlorosulfoxide **2** provides a straightforward approach to some isoprenoids.

As an illustration, biomimetic synthesis of bicyclic iridoids **14** is presented. Low-temperature treatment of the epoxide **12** with an equimolar amount of $BF_3 \cdot OEt_2$ in CH_2Cl_2 yielded >40% of a mixture of (*cis/trans*)-**14** (1 : 1, ^1H NMR, column chromatography). The reaction presumably proceeds *via* the 5-*exo*-intermediate **13**.[13] The isolated *cis*-**14** is a racemic hop ether, a component of hop essential oil.[14] Spectral properties of synthetic *cis*-**14** were almost identical; the previously reported syntheses were more complicated.[15]

In conclusion, the possibility of employing **4** and **5** as C_{10} building blocks in the synthesis of rarely occurring cyclopentanoid monoterpenes with a regular terpenoid structure **15**,[16] which is regioisomeric to iridane, is discussed.



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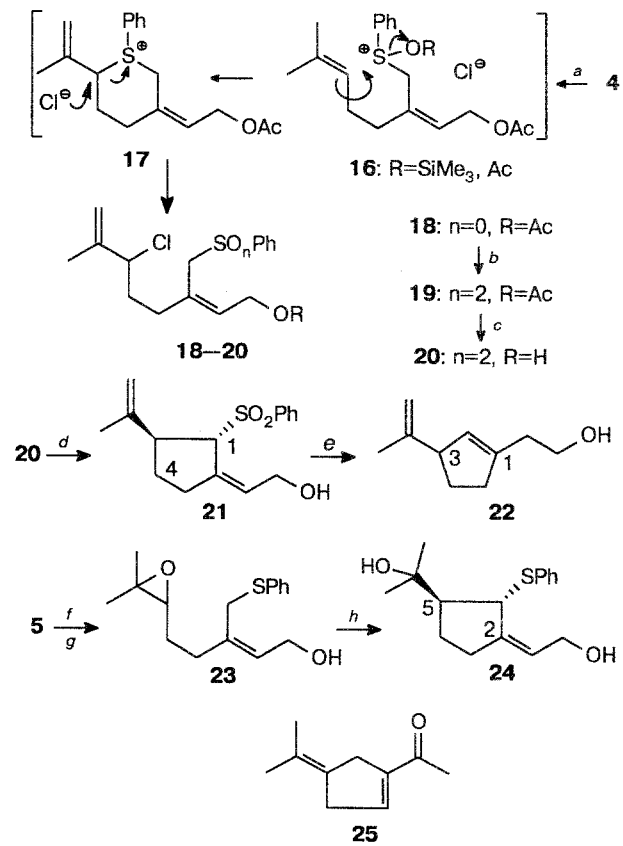
The premise for the realization of our approach is the well-known ability of «activated» sulfoxides[17] to react with external and internal C-nucleophiles to form reactive sulfonium salts.[4,18] Applied to the sulfinyl geraniol derivative **4**, «activation» with Me_3SiCl or AcCl in CH_2Cl_2 affords, under mild conditions, chlorosulfide (**18**) in ~80% yield. The latter is formed probably *via* the pre-Pummerer[4] intermediate (**16**) and the corresponding sulfonium salt (**17**), which undergoes regiospecific cleavage of the secondary C-S bond by a Cl-ion (Scheme 4).

The existence of the sulfonium salt (**17**) is highly probable, which was confirmed by its low-temperature generation from **4** and $(CF_3CO)_2O$ and $LiClO_4$ (1.5-fold excess) in CH_2Cl_2 (*cf.*[18]). The ^1H NMR spectrum in $CDCl_3$ of the thus prepared unstable perchlorate, detected by TLC, exhibited two multiplets of *o*-phenyl protons (δ~8.1) shifted downfield from the corresponding signal of chlorosulfide **18** (Δδ~0.7 ppm) and the CH_2S signal in the cyclic structure (δ~4.5) was also shifted downfield (*cf.* 3.6 ppm for linear **18**).

The sulfide **18** was selectively oxidized with MCPBA into the crystalline acetoxysulfone (**19**) (>85% yield), the

Scheme 4



a. Me_3SiCl/CH_2Cl_2, 25°C or $AcCl/CH_2Cl_2$, -60°→25°C; *b*. $MCPBA/CH_2Cl_2$, -40°→25°C; *c*. 50% H_2SO_4/MeOH, 25°C; *d*. *n*-BuLi/*n*-C_6H_{14}/THF /HMPA, -65°→25°C; *e*. NaH/THF, 25°C, then Na/EtOH, -20→25°C; *f*. NBS/THF/H_2O, 0°→25°C; *g*. $K_2CO_3/Et_2O/H_2O$ /Bu_4N^+Br, reflux; *h*. *n*-BuLi/*n*-C_6H_{14}/TMEDA/THF, -78°→0°C.

latter was quantitatively hydrolyzed into the allylic alcohol (**20**) with retention of the *(Z)*-configuration of the trisubstituted double bond (Scheme 4). The unexpectedly smooth cyclization of **20** in the presence of 2 mol. eq. of *n*-BuLi in THF/HMPA at low temperatures, yielding the unsaturated sulfone (**21**), can serve as additional evidence for the structures of **18—20** inferred from spectral data. A similar substance (**24**) was obtained under mild conditions in moderate yield from the linear epoxysulfide (**23**) by 5-*exo* cyclization[13] using 3 mol. eq. of n-BuLi in the presence of TMEDA. The epoxide **23** was obtained from **5** using the van Tamelen procedure.[19]

Thus, the allylic chloride **20** and the epoxide **23**, readily available from **4** and **5**, respectively, proved to be suitable linear precursors for the functionalized cyclopentanes **21** and **24**, respectively. Bouveault-Blanc reductive desulfonylation[20] of **21** accompanied by the allyl shift of the double bond smoothly gave a homoallylic alcohol **22**. The latter has the same cyclopentanoid skeleton as the aforementioned **15** and is similar to the acetoxycyclopentene **25** from *Eucalyptus globulus*.[21]

The structures of new compounds **21—24** were proved by spectral data and elemental analyses. The relative configurations of substituents in the sulfone **21** and the sulfide **24** follow from a distinct NOE on the HCS protons when the methyl protons in the vicinal side chain are pre-irradiated.

Experimental

Melting points were taken using a Kofler melting point hot stage and are uncorrected. IR spectra (ν , cm^{-1}) were measured in $CHCl_3$ solutions on a UR-20 instrument. UV specta were measured in EtOH on a Specord UV-VIS spectrophotometer. ^1H NMR spectra ($CDCl_3$, δ; *J*, Hz) were recorded on a Bruker WM-250 spectrometer; mass spectra (EI, 70eV) were obtained on a Varian MAT CH-6 spectrometer. TLC were performed on Silufol in hexane—ether 20:80 (v/v) unless otherwise stated.

Perillene (7). To a stirred solution of **3** (1.0 g, 3.6 mmole) in 20 ml of THF a 1.49 M solution of *n*-BuLi (4.9 ml, 7.3 mmole) in hexane was added at -85°C under Ar over 5 min, and after 10 min Me_3SiCl (0.86 g, 11.8 mmole) in 5 ml THF was added over 10 min. The reaction mixture was warmed to 25°C in 1 h and then treated with water and pentane. The aqueous layer was separated, neutralized with 50% H_2SO_4, and extracted with pentane. The combined organic layers were washed with water, dried with $MgSO_4$, and evaporated *in vacuo*. The residue (0.8 g) was purified by chromatography on silica gel (30 g). Elution with pentane gave 0.28 g (52%) of **7** as a colorless liquid, b.p. 77—78°C (15 torr), n_D^{20} 1.4734, *cf.*[6].

(*E*/*Z*)-6-Methyl-2-vinyl-1,5-heptadienyl phenyl sulfoxide (8). An emulsion of **2** (13.36 g, 45 mmol) and 20 ml of 20% NaOH in 100 ml of ether and 10 ml of MeOH was stirred for 6 h at 25°C and neutralized with 50% H_2SO_4. The aqueous layer was separated and extracted with ether. The usual workup of the combined organic layers gave 11 g of a crude product, which was chromatographed on silica gel (300 g) (a linear gradient from hexane to hexane—ether, 1:1, v/v) to yield 1.84 g (16%) of *Z*-**8** and 7.88 g (67%) *E*-**8** as colorless oils.

Z-**8**: R_f 0.53. IR (cm^{-1}): 925, 995,1050, 1085, 1380, 1445, 1480, 1660, 1575, 1660, 2870-3070. UV (λ_{max}, nm): 247 (ε 35000). ^1H NMR: 1.52 and 1.60 (br.s, 6H, CH_3), 2.1—2.4 (m, 4H, CH_2), 5.01 (br.t, 1H, HC-5, *J*=7) 5.50 (br.d, 1H, *cis*-H_2C=C, *J*=12), 5.63 (br.d, 1H, *trans*-H_2C=C, *J*=18.5), 6.09 (br.s, 1H, HCS), 7.23 (dd, 1H, HC-3, *J*=18.5 and 12), 7.4—7.7 (m, 5H, C_6H_5). MS (*m/z*): 260 $[M]^+$.

E-**8**, R_f 0.49. IR: 920, 990, 1045, 1090, 1380, 1440, 1580, 1670, 2860—3065. UV (λ_{max}, nm): 251 (ε 24200). ^1H NMR: 1.64 and 1.74 (br.s, 6H, CH_3), 2.3 and 2.8 (m., 4H, CH_2,), 5.23 (br.t, 1H, HC-5, *J*=7.5), 5.40 (br.d, 1H, *cis*-H_2C=C, *J*=11), 5.62 (br.d, 1H, *trans*-H_2C=C, *J*=17.5), 6.21 (br.s, 1H, HCS), 6.27 (dd, 1H, HC=C, *J*=17.5 and 11), 7.4—7.7 (m, 5H, C_6H_5). MS (*m/z*): 260 $[M]^+$. Found, %: C 73.59; H 7.85; S 12.16. $C_{16}H_{20}OS$. Calculated,%: C 73.80; H 7.74; S 12.31.

7-Methyl-3-methylene-1-phenylthio-6-octen-2-ol (11). Method A. To a stirred solution of PhSNa [prepared from Na (0.26 g, 11.3 mg-atom) and PhSH (1.25 g, 11.3 mmol) in 10 ml of MeOH] a solution of **8** (1.14 g, 4.38 mmol) in 5 ml of MeOH was added in one portion under Ar at 25°C. The reaction mixture was refluxed for 3 h, then cooled, diluted with ether, the organic layer was separated, washed with 5% NaOH, a saturated solution of NH_4Cl, and water, dried with $MgSO_4$, and evaporated *in vacuo* to yield 1.5 g of a crude product. Chromatographic separation (a linear gradient from hexane to hexane — ether 4:1, v/v) on silica gel (50 g) gave 0.69 g (60% yield) of **11** as a colorless oil, R_f 0.50 (hexane—ether, 7:3). IR: 910, 1005, 1030, 1070, 1175, 1235, 1330, 1380, 1440, 1485, 1590, 1650, 2860—3080, 3530, 3615. ^1H NMR: 1.62 and 1.71 (br.s, 6H, CH_3), 2.0—2.2 (m, 4H, CH_2), 3.11 (AB part of ABX spin system, 2H, HCS, J_{AB} = 13.5, J_{AX} = 8.5, J_{BX} = 4), 4.17 (X part of ABX spin system, 1H, HCO, J_{AX} = 8.5, J_{BX} = 4), 4.96 and 5.17 (br.s, 2H, H_2C=C), 5.15 (m, 1H, HC=C), 7.2—7.4 (m, 5H, C_6H_5). MS (*m/z*): 262 $[M]^+$. Found,%: 73.63; H 8.57; S 12.06. $C_{16}H_{22}OS$. Calculated, %: C 73.23; H 8.45; S 12.22. Mol. weight 262.4.

Method B. To a stirred solution of PhSNa [prepared from Na (2.76 g, 0.12 mg-atom) and PhSH (13.22 g, 0.12 mmol) in 50 ml of MeOH] a solution of **2** (13.36 g, 45 mmol) in 10 ml of MeOH was added over 5 min under Ar at -50°C. The reaction mixture was heated over 1 h to boiling, then refluxed for 4 h. Following workup and chromatographic separation performed as in the above experiment, **11** (7.1 g, 60% yield) was obtained. The product was nearly identical (TLC, ^1H NMR) with that prepared according to method A.

2-Methyl-6-methylene-7,8-epoxyoct-2-ene (12). To a stirred solution of **11** (2.58 g, 9.8 mmol) in 10 ml of CH_2Cl_2 was added $Me_3O^+BF_4^-$ (2.2 g, 14.9 mmol) in one portion at −10°C under Ar. The reaction mixture was warmed over 0.5 h up to 25°C, kept at 25°C for 2 h, then treated with 15 ml of 5% NaOH and 30 ml of pentane at 0°C. The mixture was warmed up to 25°C over 1 h, the aqueous layer was separated, neutralized with 10% H_2SO_4, and extracted with pentane. The usual workup of the combined organic layers gave 2 g of a crude product. Chromatographic purification (a linear gradient, from hexane to hexane — ether 9:1, v/v) on silica gel (50 g) gave 1.15 g (51% yield) of **12** as a colorless liquid, b.p. 78—79°C (10 torr), n_D^{20} 1.4670. IR: 905, 1110, 1250, 1380, 1450, 1645, 2860—3050, 3085. ^1H NMR: 1.61 and 1.68 (br.s, 6H, CH_3), 1.9—2.2 (m, 4H, CH_2), 2.76 (AB part of ABX spin system, 2H, CH_2O, J_{AB}=6.5, J_{AX} = 4, J_{BX} = 3), 3.40 (X part of ABX spin system, 1H, HCO, J_{AX} = 4, J_{BX} = 3), 4.97 and 5.16 (br.s, 2H, H_2C=C), 5.12 (br.t, 1H, HC=C, *J*=8.5). MS (*m/z*): 152 $[M]^+$. Found, %: C 78.60; H 10.46. $C_{10}H_{16}O$. Calculated, %: C 78.89; H 10.59. Mol. weight 152.2.

(±)-Hop ether (*cis*-14) and (±)-2,2-dimethyl-6-methylene-3-oxabicyclo[3.3.0]octane (*trans*-14). To a stirred solution of **12** (0.84 g, 5.5 mmol) in 6 ml of CH_2Cl_2 a solution of $F_3B{\cdot}OEt_2$ (0.78 g, 5.5 mmol) in 3 ml of CH_2Cl_2 was added at −78°C under Ar. The reaction mixture was stirred for 15 min at −78°C, then treated with Py (0.44 g, 5.6 mmol) in 5 ml of pentane. The resulting mixture was heated up to 25°C and pentane and water were added. The aqueous layer was separated and extracted with pentane. The usual workup of the combined organic layers gave 0.8 g of a crude product. Its chromatographic separation (a linear gradient, from pentane to pentane—ether, 9 : 1, v/v) on silica gel (30 g) gave 0.18 g (21% yield) of *cis*-**14** as a colorless liquid, b.p. 69—71°C (11 Torr), n_D^{20}

1.4712, and 0.18 g (21% yield) of *trans*-**14** as a colorless liquid, b.p. 67—68°C (11 torr), n_D^{20} 1.4689. *trans*-**14**. IR: 885, 980, 1005, 1130, 1155, 1200, 1275, 1380, 1435, 1465, 1660, 2860—2970, 3080. ^{1}H NMR: 1.15 and 1.30 (s, 6H, CH_3), 1.45—1.7 (m, 2H, HC-8), 2.0 (m, 1H, HC-1), 2.6—3.0 (m, 3H, HC-5, HC-7), 3.71 (AB part of ABX spin system, 2H, HC-4, $J_{AB}=J_{AX}=7.5$, $J_{BX}=10$), 4.6 and 4.7 (m, 2H, H_2C=C). ^{13}C NMR ($CDCl_3$, δ): 22.3 (C-8), 23.4 and 28.7 (CH_3), 37.1 (C-7), 56.0 (C-1), 61.6 (C-5), 65.9 (C-4), 77.1 (C-2), 103.9 (H_2C=C), 147.9 (C-6). MS (*m/z*): 152 $[M]^+$, 122, 107, 94, 79, 68.

1-Acetoxy-7-methyl-3-phenylthiomethyl-6-chloro-2(*Z*),7-octadiene (18). Method A. To a stirred solution of **4** (0.19 g, 0.59 mmol) in 2 ml of CH_2Cl_2 was added Me_3SiCl (0.28 g, 3.83 mmol) in one portion at 25°C under Ar. The reaction mixture was left at 25°C for 17 h, then the solvent was evaporated *in vacuo* and the residue (0.2 g) was chromatographed on silica gel (15 g), a linear gradient from hexane to hexane—ether, 4:1, v/v, to give 0.17 g (85% yield) of **18** as a colorless oil, R_f 0.57 (hexane—ether, 7:3, v/v). IR: 915, 965, 1030, 1090, 1245, 1370, 1440, 1480, 1590, 1660, 1730, 2860—3025, 3085. 1H NMR: 1.82 (br.s, 3H, CH_3), 2.01 (s, 3H, CH_3CO), 2.0—2.3 (m, 4H, CH_2), 3.57 (br.s, 2H, HCS), 4.32 (d, 2H, CH_2O, *J*=7), 4.36 (br.t, 1H, HCCl, *J*=8), 4.91 and 5.03 (br.s, 2H, H_2C=C), 5.46 (br.t, 1H, HC=C, *J*=7), 7.2—7.4 (m, 5H, C_6H_5). Found, %: C 63.84; H 7.05; Cl 10.78; S 9.70. $C_{18}H_{23}ClO_2S$. Calculated,%: C 63.79, H 6.84; Cl 10.46; S 9.46.

Method B. To a stirred solution of **4** (0.85 g, 2.64 mmole) in 6 ml of CH_2Cl_2, acetyl chloride (0.26 g, 3.31 mmole) was added in one portion at -60°C under Ar. The reaction mixture was heated up to 25°C in 0.5 h, kept at 25°C for 2 h, and then treated as usual. Chromatographic purification (*vide supra*) of the residue (1.2 g) gave 0.67 g (67% yield) of **18** practically identical with that prepared by the method A (TLC, ^{1}H NMR).

1-Acetoxy-7-methyl-3-phenylsulfonylmethyl-6-chloro-2*Z*,7-octadiene (19). To a stirred solution of **18** (2.55 g, 7.5 mmol) MCPBA (2.7 g, 15.7 mmol) was added over 5 min at −40°C under Ar. The reaction mixture was heated up to 25°C in 1 h, then ether and a saturated aqueous solution of $NaHCO_3$ were added. The aqueous layer was separated and extracted with ether. The usual workup of the combined organic layers gave 3.2 g of a crude product, whose chromatographic purification on silica gel (100 g, linear gradient from hexane to hexane—ether, 1:1, v/v) gave 2.39 g (86% yield) of **19** as white crystals, m.p. 65—66°C (hexane—ether). IR: 910, 960, 1025, 1090, 1160, 1230, 1325, 1370, 1450, 1650, 1745, 2900—3020, 3080. ^{1}H NMR: 1.7—2.2 (m, 4H, CH_2) 1.76 (br.s, 3H, CH_3), 2.02 (s, 3H, CH_3CO), 3.91 (br.s, 2H, HCS), 4.26 (br.t, 1H, HCCl, *J*=6.5), 4.35 (d, 2H, CH_2O, *J*=7), 4.87 and 4.97 (br.s, 2H, H_2C=C), 5.86 (br.t, 1H, HC=C, *J*=7), 7.5—7.9 (m, 5H, C_6H_5). Found,%: C 58.58; H 6.33; Cl 9.44; S 8.51. $C_{18}H_{23}ClO_4S$. Calculated,%: C 58.29; H 6.25; Cl 9.56; S 8.64.

7-Methyl-3-phenylsulfonylmethyl-6-chlorooct-2*Z*,7-octadien-1-ol (20). A solution of **19** (1.93 g, 5.2 mmol) and 0.3 ml of 50% H_2SO_4 in 15 ml of MeOH was kept at 25°C for 36 h. After addition of a saturated solution of $NaHCO_3$ and ether the aqeous layer was separated and extracted with ether. The usual workup of the combined extracts gave 1.7 g of a crude product. Chromatographic purification (a linear gradient, from hexane to ether) on silica gel (50 g) afforded 1.66 g (97% yield) of **20** as a colorless oil, R_f 0.38. IR: 905, 1015, 1085, 1120, 1145, 1325, 1450, 1650, 2870—2980, 3540, 3620. ^{1}H NMR: 1.8—2.3 (m, 4H, CH_2), 1.85 (br.s, 3H, CH_3), 3.92 (br.s, 2H, HCS), 3.97 (d, 2H, CH_2O, *J*=7), 4.27 (br.t, 1H, HCCl, *J*=6.5), 4.86 and 4.97 (br.s, 2H, H_2C=C), 5.85 (br.t, 1H, HC=C, *J*=7), 7.6—7.9 (m, 5H, C_6H_5). MS (*m/z*): 310 $[M-H_2O]$, 294, 275, 187, 151, 143, 133, 125, 107, 97, 79, 71, 69.

***trans*-5-Isopropenyl-2*Z*-(2-hydroxyethylidene)-1-(phenylsulfonyl)cyclopentane (21).** To a stirred solution of **20** (1.8 g, 5.47 mmol) in 20 ml of THF and 5 ml of HMPA, a 1.77 *M* solution of *n*-BuLi (7 ml, 12.4 mmol) in hexane was added over 15 min at −65°C under Ar. The reaction mixture was heated up to 25°C in 2 h and then treated with a saturated $NaHCO_3$ solution and ether. The usual workup of the combined organic extracts gave 1.5 g of a crude product. Chromatographic purification on 50 g of silica gel (linear gradient from hexane to ether) gave 1.08 g (68% yield) of **21** as white crystals, m.p. 80.5—81°C (hexane—ether). IR: 900, 1020, 1090, 1150, 1305, 1400, 1650, 2890—2980, 3080, 3540, 3630. 1H NMR: 1.49 (br.s, 3H., CH3), 1.5—2.0 (m, 2H, CH-4), 2.4 (m, 2H, CH-3), 3.07 (br.dt., HC-5, *J*=8 and 4.5), 4.14 (br.t, 2H, CH_2O, *J*=7.5), 4.29 (br.d, 1H, HCS, *J*=4.5), 4.40 and 4.54 (br.s, 2H, H_2C=C), 6.00 (br.t, 1H, HC=C, *J*=7.5), 7.5—7.9 (m, 5H, C_6H_5). Found,%: C 65.56; H 6.95; S 10.74. $C_{16}H_{20}O_3S$. Calculated,%: C 65.73; H 6.89; S 10.96.

3-Isopropenyl-2-(2-hydroxyethyl)cyclopentene (22). A suspension of NaH (48 mg, 2 mmol) and **21** (0.6 g, 2 mmol) in 10 ml of THF was stirred at 25°C for 30 min under Ar. Ethanol (0.46 g, 10 mmole) and Na (0.23 g, 10 mg-atom) were carefully added at −20°C over 10 min. The reaction mixture was heated up to 25°C in 1.5 h, stirred at 25°C for 1 h, diluted with hexane and neutralized with 10% H_2SO_4. The aqueous layer was separated and extracted with hexane. The usual workup of the combined organic layers gave 0.3 g of a crude product. Chromatographic purification on 15 g of silica gel (linear gradient from hexane to hexane—ether, 4:1, v/v) gave 0.16 g (51% yield) of **22** as a colorless liquid, b.p. 73—74°C (1.5 Torr), n_D^{20} 1.4911. IR: 890, 1050, 1225, 1375, 1440, 1645, 2800—3000, 3080, 3640. ^{1}H NMR: 1.67 (br.s, 3H, CH_3), 1.7—2.4 (m, 6H, CH_2), 3.3 (m, 1H, HC-3), 3.72 (t, 2H, CH_2O, *J*=13.5), 4.65 (m, 2H, H_2C=C), 5.37 (br.s, 1H, HC-2). MS (*m/z*): 152 $[M]^+$. Found, %: C 78.86; H 10.75. $C_{10}H_{16}O$. Calculated,%: C 78.89; H 10.60. Molecular weight 152.2.

7-Methyl-3-phenylthiomethyl-6,7-epoxy-2*Z*-octen-1-ol (23). A solution of **5** (3.14 g, 12 mmol) and NBS (2.3 g, 12.9 mmol) in 30 ml of THF and 10 ml of H_2O was stirred at 0°C for 30 min, then heated up to 25°C and diluted with ether. The aqueous layer was separated and extracted with ether. The combined extracts were washed with water and evaporated *in vacuo*. The oily residue (4 g) was dissolved in ether (40 ml) and heated with *n*-Bu_4NBr (0.32 g, 1 mmol) and K_2CO_3 (6.0 g, 43.4 mmol) in water (10 ml) under reflux with stirring. The usual workup gave 3.2 g of a crude product. The chromatographic purification (a linear gradient from hexane to hexane—ether, 2:3, v/v) on silica gel (100 g) afforded 2.3 g of **23** (69% yield) as a colorless oil, R_f 0.69 (ether). IR: 870, 900, 1000, 1070, 1090, 1125, 1325, 1380, 1440, 1470, 1580, 1650, 2870—3060, 3430, 3575, 3615. ^{1}H NMR: 1.23 and 1.26 (s, 6H, CH_3), 1.7 (m, 2H, HC-5), 2.33 (br.t, 2H, HC-4, *J*=7), 2.73 (t, 1H, HCO, *J*=6), 3.53 (br.s, 2H, HCS), 3.87 (d, 2H, CH_2O, *J*=8), 5.53 (br.t, 1H, HC=C, *J*=8), 7.3 (m, 5H, C_6H_5). MS (*m/z*): 278$[M]^+$. Found,%: C 69.39; H 7.78; S 11.40. $C_{16}H_{22}O_2S$. Calculated,%: C 69.03; H 7.97; S 11.51. Molecular weight 278.4.

***trans*-5-(1-Hydroxy-1-methylethyl)-2*Z*-(2-hydroxyethylidene)-1-phenylthiocyclopentane (24).** To a stirred solution of **23** (1.52 g, 5.46 mmol) and TMEDA (2.31 g, 19.9 mmol) in 30 ml of THF, a 1.92 *M* solution of *n*-BuLi (9 ml, 17.3 mmole) in hexane was added at −70°C over 10 min under Ar. The reaction mixture was kept for 5 h at −70°C, then warmed to 0°C, and decomposed with a saturated NH_4Cl solution. The aqueous layer was separated and extracted with ether. The usual workup of the combined organic layers gave 1.6 g of a crude product. Chromatographic purification (a linear gradient from hexane to ether) on silica gel (50 g) afforded 0.35 g of unreacted **23** and 0.36 g (31% yield) of **24** as white crystals, m.p. 84—85°C (hexane—ether). IR: 950, 1000, 1060, 1115, 1230, 1350, 1385, 1435, 1675, 2875—3020, 3435, 3610. ^{1}H NMR: 1.02 and

1.25 (s, 6H, CH_3), 1.5—1.9 (m, 2H, CH-4), 2.1 (m, 1H, HC-5), 2.2—2.5 (m, 2H, CH-3), 3.4—3.7 (m, 2H, CH_2O), 4.14 (br.d, 1H, HCS, J=3.5), 5.48 (br.t, 1H, HC=C, J=7.5), 7.3—7.6 (m, 5H, C_6H_5). MS (m/z): 278 $[M]^+$. Found,%: C 68.59; H 7.94; S 11.59. $C_{16}H_{22}O_2S$. Calculated, %: C 69.03; H 7.97; S 11.51. Molecular weight 278.4.

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Michael reactions with *trans*-3-isopropenyl-2-phenylthiocyclopentan-1-one and *trans*-3-isopropenyl-2-phenylsulfonylcyclopentan-1-one

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The condensation of methyl acrylate with the title β-ketosulfide and β-ketosulfone was studied. The primary adduct of β-ketosulfone with acrolein readily undergoes intramolecular aldolization to give bicyclo[3.2.1]octane derivatives. The molecular structure of one of them was elucidated by X-ray analysis.

Key words: cyclopentanone, β-ketosulfide, β-ketosulfone, Michael reaction, methyl acrylate, acrolein, bicyclo[3.2.1]octane, derivatives, X-ray analysis.

As a continuation of our studies aimed at the elaboration of new approaches to the synthesis of cyclopentanoid terpenes we discuss here the use of the easily accessible ketosulfide (**1**) and ketosulfone (**2**)[1—3] as CH-components in a Michael reaction with methyl acrylate and acrolein and some properties of the products obtained thereby.

The reaction of ketosulfide **1** with methyl acrylate catalyzed by *tert*-BuOK in THF afforded a mixture of stereoisomeric ketoesters (**3**) (Scheme 1) in a more than 80% yield. The *trans/cis* ratio ~2:3 was determined on the basis of ^1H NMR and by chromatographic separation of the isomers on silica. Replacement of *tert*-BuOK by MeONa resulted in a decrease in the yield of **3** due to formation of unidentified by-products and polymerization of methyl acrylate. Michael addition of **2** to methyl acrylate could only be realized in the presence of 1,8-diazabicyclo[4.5.0]undec-7-ene (DBU) in THF, and only *cis*- **4** was formed stereospecifically in ~35% yield.

Structures of the previously unknown compounds **3** and **4** were established on the basis of their elemental analysis and spectral data, in particular, on the basis of ^1H NOE measurements. When *syn*-olefinic H for *trans*-**3** (δ 4.79) was pre-irradiated, a clear NOE was observed on the β-methylene protons of the methoxycarbonylethyl

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