Chemistry of Natural Compounds, Vol. 47, No. 1, March, 2011 [Russian original 47, No. 1, January–February, 2011]

SYNTHESIS OF SEVERAL OPTICALLY ACTIVE MENTHANE DISULFIDES AND THIOSULFINATES

E. S. Izmest′ev, D. V. Sudarikov,* S. A. Rubtsova, and A. V. Kuchin

UDC 547.425.2

Symmetric and asymmetric disulfides were synthesized from mixtures of menthyl- and neomenthylthiols and were oxidized asymmetrically. Dineomenthyldisulfide, dimenthyldisulfide, and menthylneomenthyldisulfide were synthesized in yields of 47–48%, 24-25, and 29-55, respectively. Pure diastereomeric dimenthyl-, dineomenthyl-, and menthylneomenthylthiosulfinates were synthesized in yields of 85–90% and de *up to 30%.*

Keywords: dimenthyldisulfide, dineomenthyldisulfide, menthylneomenthyldisulfide, thiosulfinate, asymmetric oxidation.

Terpene mercaptans and their transformation products such as disulfides and thiosulfinates are of great chemical interest because of their practical applications. Disulfides are used in the chemistry of high-molecular-weight compounds as initiators of radical polymerization reactions [1]; as chiral ligands in nucleophilic addition of organozinc compounds to aldehydes [2]; as intermediates for preparing pesticides, drugs, and dyes; and in organic synthesis [3]. The use of thiosulfinates is much more widely discussed in the literature [4]. They are active human circulatory agents and prevent the formation of thrombs [5].

Oxidation of *l*-menthol (**1**) produced *l*(1*R*,4*S*)-menthone (**2**) [6], which was transformed into (6*S*,9*R*)-6-isopropyl-9-methyl-1,4-dithiospiro[4.5]decane (dithiolane-*l*-menthone) (**3**) by reaction with 1,2-ethanedithiol in the presence of the Lewis acid $BF_3 \cdot Et_2O$ [7]. The yields of **2** and **3** were 94 and 97%, respectively. The produced **3** was reduced by *n*-butyllithium by the literature method [8] to a mixture of mercaptans consisting of neomenthylthiol (**4a**) and menthylthiol (**4b**) in a 65:35 ratio.

However, it was previously reported [8] that the reduction leads to the formation of the single product **4b** in 81% yield, low-resolution PMR spectra and mass spectra of which were given as proof although the results could not determine unambiguously which mercaptan was obtained from the reduction.

PMR and ^{13}C NMR spectra showed that the principal reaction product was **4a**, in which the thio group occupies an axial position relative to the cyclohexane ring and not **4b**, in which the thio group occupies an equatorial position, as suggested previously. The ^{13}C NMR spectrum exhibited 10 strong resonances belonging to **4a** and 10 weak ones belonging to **4b**. The PMR spectrum of **4b** gave a broad multiplet for the H atoms on the first and second C atoms because of their diaxial orientation. It is known that the spin–spin coupling constant (SSCC) increases if the torsion angle of H atoms is increased [9]. In contrast with **4b**, the axial–equatorial coupling of the analogous atoms in **4a** compresses the multiplet into a broad singlet as a result of the decreased SSCC. The PMR spectrum of a mixture of **4a** and **4b** exhibited doublets characteristic of SH groups at 1.25 and 1.33 ppm, respectively.

Pure thiol **4a** could be partially isolated by column chromatography over silica gel using petroleum ether as the eluent.

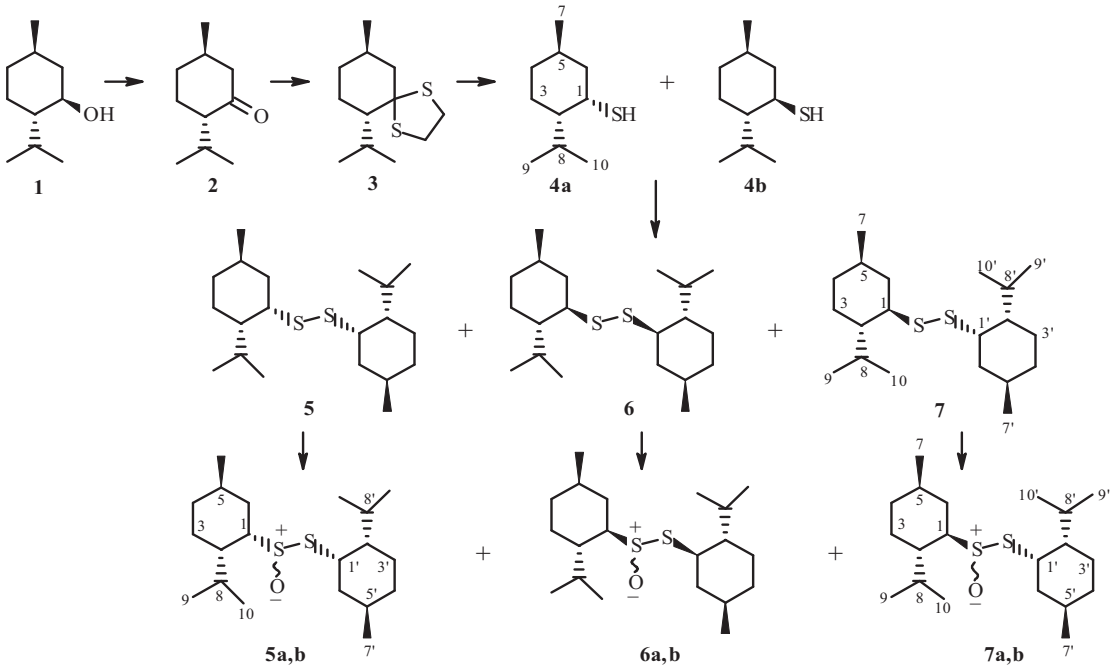
We also synthesized three stereoisomeric menthane disulfides via mild oxidation of a mixture of neomenthylthiol (**4a**) and menthylthiol (**4b**) by various oxidants.

Oxidation of the mixture of **4a** and **4b** by iodine in EtOH probably occurred through a free-radical mechanism with complete conversion and formation of the three stereoisomeric disulfides dineomenthyldisulfide (**5**), dimenthyldisulfide (**6**), and menthylneomenthyldisulfide (**7**). The principal product was disulfide **5**, which was formed in 47% yield. The yields of **6** and **7** were 24 and 29%, respectively.

Oxidation of the thiols by $FeCl_3$ converted them completely to the disulfides in the same yields.

Institute of Chemistry, Komi Scientific Center, Ural Branch, Russian Academy of Sciences, 167982, Syktyvkar, fax: (8212) 43 66 77, e-mail: sudarikov-dv@chemi.komisc.ru. Translated from *Khimiya Prirodnykh Soedinenii*, No. 1, pp. 43–47, January–February, 2011. Original article submitted June 28, 2010.

 0009-3130/11/4701-0046



Oxidation by PBr_5 occurred differently. The principal products were disulfide **7** in 55% yield and disulfide **6** in 9% yield. Disulfide **5** was not detected. This may have been due to a change of the oxidation mechanism and steric hindrances arising upon coordination of the thiols to the oxidant.

All oxidation reactions of the mercaptans occurred at room temperature with 100% conversion. Diastereomeric disulfides were separated by column chromatography over silica gel.

In contrast with mercaptans, the resonance of the first C atom in the ^{13}C NMR spectrum of the disulfides was shifted to weak field. The doublets characteristic of the SH groups disappeared in the PMR spectrum.

The PMR and ^{13}C NMR spectra of disulfides **5** and **6** showed a single set of resonances. Compound **7** is asymmetric and contains menthyl and neomenthyl moieties so that the resonances of the C atoms are not superimposed. Therefore, resonances of both the menthyl and neomenthyl moieties are clearly discernable in the spectrum.

The resulting diastereomeric disulfides were oxidized by *m*-chloroperoxybenzoic acid (*m*-CPBA) into the thiosulfinates in yields up to 90%. Oxidation of **5** formed dineomenthylthiosulfinates (**5a** and **5b**) in *de* 28%. The dimenthylthiosulfinates (**6a** and **6b**) were obtained with *de* 20%. Oxidation of asymmetric **7** occurred at the S atom directly bonded to the C atom of the menthyl moiety. The resonance of the first C atom bonded to the neomenthyl moiety was shifted to weak field in the ^{13}C NMR spectra. The S atom in the neomenthyl moiety was probably shielded by the isopropyl group situated on the same side of the cyclohexane ring. The neomenthylmenthylthiosulfinates (**7a** and **7b**) were formed with *de* 2.6%. All thiosulfinates could be separated by column chromatography over silica gel.

EXPERIMENTAL

IR spectra were recorded as thin layers or in KBr pellets on a Shimadzu IR Prestige 21 IR-Fourier spectrometer. Melting points were determined on a Gallenkamp–Sanyo instrument. PMR and ^{13}C NMR spectra were recorded in $CDCl_3$ solution with TMS internal standard on a Bruker Avance-300 (300.17 MHz for ^1H and 75.48 MHz for ^{13}C) spectrometer. Resonances of ^1H and ^{13}C were assigned using two-dimensional homo- (^1H–^1H COSY, ^1H–^1H NOESY) and heteronuclear experiments (^1H–^{13}C HSQC). Diastereomeric excesses were calculated from PMR data using the ratio of integrated intensities of H atoms resonances from the first C atom bonded to the sulfinyl group. Optical rotation angles were measured on a Kruss automated digital P3002RS polarimeter. TLC was carried out on Silufol and Sorbfil plates using solvent system C_7H_{16}:Et_2O with vanillin in EtOH and $KMnO_4$ for detection. Elemental analysis was performed using an EA 1110 CHNS-O automated analyzer.

Compound **2** was prepared by oxidation of **1** {$[\alpha]_D$ +50° (*c* 10.0, EtOH)} by $K_2Cr_2O_7$ in acidic medium [6] in 94% yield; **3**, from **2** by the published method in 97% yield [7].

The diastereomeric mixture of menthylthiols was synthesized by the literature method [8] in overall yield 78% and *de* 30%.

(1*S*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexanethiol (4a) was isolated by column chromatography over silica gel [petroleum ether eluent, $KMnO_4$ detection; R_f = 0.38 (**4a**), 0.36 (**4b**)], $[\alpha]_D^{22}$ +52.9° (*c* 0.8, EtOH).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.81–0.95 (1H, m, H-4e), 0.90 (3H, d, J = 6.3, Me-7), 0.92 (6H, d, J = 6.6, Me-9, Me-10), 1.01–1.11 (1H, m, H-2), 1.25 (1H, d, J = 7.0, SH), 1.26–1.43 (1H, m, H-3e), 1.36–1.47 (1H, m, H-6e), 1.45–1.60 (1H, m, H-8), 1.67–1.76 (1H, m, H-3a), 1.70–1.80 (1H, m, H-4a), 1.76–1.90 (1H, m, H-5), 1.85–1.93 (1H, m, H-6a), 3.50–3.56 (1H, m, H-1).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 20.39 (C-9), 20.88 (C-10), 22.17 (C-7), 24.19 (C-3), 25.96 (C-5), 30.33 (C-8), 35.30 (C-4), 40.20 (C-1), 44.04 (C-6), 48.26 (C-2). $C_{10}H_{20}S$. Isolated partially. Overall yield of the diastereomers, 78%.

Oxidation of Mixture of Diastereomeric Mercaptans by PBr_5. A solution of the mixture of diastereomeric **4a** and **4b** (0.172 g, 1 mmol, 65:35 ratio) in heptane (3 mL) was stirred, treated slowly dropwise with PBr_5 (0.215 g, 0.5 mmol) in heptane (7 mL), treated after 24 h again with PBr_5 (0.1 g) in heptane (10 mL), stirred for another 24 h, washed with H_2O, and extracted with petroleum ether (3 × 15 mL). The combined organic layers were dried over anhydrous $MgSO_4$ and filtered. The solvent was vacuum distilled. The solid was separated by column chromatography over silica gel (heptane eluent, vanillin detection).

If the PBr_5 was added rapidly, the yield of principal product (**7**) did not change, the yield of **6** decreased by almost three times, and the amount of side products increased.

Oxidation of the Mixture of Diastereomeric Mercaptans by I_2. The mixture of diastereomeric mercaptans (0.172 g, 1 mmol) in EtOH (4 mL) was stirred vigorously, treated very slowly dropwise with I_2 (0.127 g, 0.5 mmol) in EtOH (6 mL), stirred for 5 h, treated slowly with a two-fold excess of I_2, and stirred for another 48 h. The EtOH was vacuum distilled. The solid was dissolved in $CHCl_3$ (30 mL), washed with saturated $Na_2S_2O_3$ solution (3 × 15 mL), and dried over anhydrous $MgSO_4$. The solvent was vacuum distilled. The solid was separated by column chromatography (heptane eluent, vanillin detection). R_f(**5**) 0.46, R_f(**7**) 0.39, R_f(**6**) 0.30.

Oxidation of the Mixture of Diastereomeric Mercaptans by $FeCl_3$. The mixture of diastereomeric mercaptans (0.172 g, 1 mmol) in EtOH (4 mL) was stirred, treated dropwise with $FeCl_3 \cdot 6H_2O$ (0.405 g, 1.5 mmol) in EtOH (6 mL), and stirred for 4 h. The solvent was vacuum distilled. The solid was dissolved in H_2O (30 mL) and extracted with petroleum ether (3 × 15 mL). The extract was dried over anhydrous $MgSO_4$. The solvent was vacuum distilled. The solid was separated by column chromatography (heptane eluent, vanillin detection).

1,2-*bis*[(1*S*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexyl)disulfide (5), mp 52.4°C, $[\alpha]_D^{22}$ +350.00° (*c* 1.00, acetone).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.83–0.97 (2H, m, H-4a, 4a′), 0.92 (6H, d, J = 6.6, Me-7, 7′), 0.93 (6H, d, J = 6.6, Me-9, 9′), 1.00 (6H, d, J = 6.6, Me-10, 10′), 1.12–1.26 (2H, m, H-6a, 6a′), 1.13–1.26 (2H, m, H-2, 2′), 1.14–1.28 (2H, m, H-3a, 3a′), 1.64–1.77 (2H, m, H-8, 8′), 1.68–1.77 (2H, m, H-3e, 3e′), 1.71–1.83 (2H, m, H-4e, 4e′), 1.85–1.95 (2H, m, H-5, 5′), 2.29–2.40 (2H, m, H-6e, 6e′), 3.21–3.29 (2H, m, 2H-1).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 20.62 (C-9, 9′), 21.20 (C-10, 10′), 22.20 (C-7, 7′), 25.87 (C-3, 3′), 26.18 (C-5, 5′), 29.93 (C-8, 8′), 35.47 (C-4, 4′), 39.77 (C-6, 6′), 48.75 (C-2, 2′), 52.56 (C-1, 1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2$. Yield 47%.

1,2-*bis*[(1*R*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexyl]disulfide (6), $[\alpha]_D^{22}$ –262.69° (*c* 0.68, acetone).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.82 (3H, d, J = 6.9, Me-9′), 0.82–1.01 (2H, m, H-4a, 4a′), 0.91 (3H, d, J = 5.8, Me-7), 0.93 (6H, d, J = 6.8, Me-10, 10′), 0.96 (3H, d, J = 6.8, Me-7′), 1.03 (3H, d, J = 6.5, Me-9), 0.98–1.13 (1H, m, H-3a′), 1.11–1.24 (1H, m, H-2), 1.11–1.27 (1H, m, H-6a′), 1.14–1.28 (1H, m, H-6a), 1.15–1.33 (1H, m, H-3a), 1.20–1.31 (1H, m, H-2′), 1.34–1.49 (1H, m, H-5′), 1.65–1.79 (1H, m, H-8), 1.66–1.79 (2H, m, H-3e, 3e′), 1.69–1.82 (2H, m, H-4e, 4e′), 1.83–1.98 (1H, m, H-5), 2.22–2.32 (1H, m, H-6e′), 2.24–2.34 (1H, m, H-6e), 2.34–2.46 (1H, m, H-8′), 2.53–2.66 (1H, m, H-1), 3.30–3.36 (1H, m, H-1′).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 15.38 (C-9′), 21.03 (C-9), 21.26 (C-10, 10′), 22.18 (C-7), 22.38 (C-7′), 24.60 (C-3′), 25.57 (C-3), 26.18 (C-5), 27.38 (C-8′), 29.95 (C-8), 33.36 (C-5′), 34.65 (C-4′), 35.45 (C-4), 39.87 (C-6′), 43.12 (C-6), 46.94 (C-2′), 49.04 (C-2), 52.75 (C-1), 53.92 (C-1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2$. Yield 24%.

1-[(1*R*,2*S*,5*R*)-2-Isopropyl-5-methylcyclohexyl]-2-[(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl]disulfide (7), $[\alpha]_D^{22}$ –1.46° (*c* 1.10, acetone).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.82 (6H, d, J = 7.0, Me-9, 9′), 0.85–0.99 (2H, m, H-4a, 4a′), 0.95 (6H, d, J = 7.1, Me-10, 10′), 0.95 (6H, d, J = 6.4, Me-7, 7′), 0.99–1.15 (2H, m, H-3a, 3a′), 1.09–1.25 (2H, m, H-6a, 6a′), 1.14–1.28 (2H, m, H-3a, 3a′), 1.09–1.25 (2H, m, H-6a, 6a′), 1.14–1.28 (2H, m, H-3a, 3a′), 1.21–1.34 (2H, m, H-2, 2′), 1.32–1.49 (2H, m, H-5, 5′), 1.68–1.80 (2H, m, H-3e, 3e′), 1.69–1.81 (2H, m, H-4e, 4e′), 2.24–2.35 (2H, m, H-6e, 6e′), 2.36–2.51 (2H, m, H-8, 8′), 2.47–2.60 (2H, m, 2H-1).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 15.40 (C-9, 9′), 21.27 (C-10, 10′), 22.34 (C-7, 7′), 24.61 (C-3, 3′), 27.30 (C-8, 8′), 33.38 (C-5, 5′), 34.66 (C-4, 4′), 43.12 (C-6, 6′), 46.68 (C-2, 2′), 53.01 (C-1, 1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2$. Yield 29%.

Oxidation of Disulfides by *m*-Chloroperoxybenzoic Acid (*m*-CPBA). A solution of disulfide (0.342 g, 1 mmol) in dichloromethane (DCM, 25 mL) was cooled to –10°C, stirred vigorously, treated dropwise with a solution of *m*-CPBA (0.246 g, 1 mmol, 70%) in DCM (25 mL), stirred continuously for 5 h, and treated with dry gaseous NH_3 through a tube. The resulting flocculent ammonium salt was filtered off. The solvent was vacuum distilled. The solid was separated by column chromatography over silica gel.

The solvent was selected depending on the type of thiosulfinate product. Diastereomeric dineomenthylthiosulfinates and menthylneomenthylthiosulfinates were separated using a heptane:Et_2O (5:1) mixture. Diastereomeric dimenthylthiosulfinates were partially separated using a petroleum ether:Et_2O (100:1) mixture.

First diastereomer of [(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (5a), $[\alpha]_D^{22}$ –36.40° (*c* 1.10, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1076.28 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm): 0.85–1.01 (2H, m, H-4a, 4a′), 0.88–0.99 (18H, m, Me-7, 7′; Me-9, 9′; Me-10, 10′), 0.94–1.11 (1H, m, H-3a), 1.14–1.27 (1H, m, H-2), 1.29–1.41 (1H, m, H-2′), 1.34–1.48 (1H, m, H-6a′), 1.39–1.52 (1H, m, H-6a), 1.45–1.60 (1H, m, H-8), 1.49–1.63 (1H, m, H-3a′), 1.71–1.90 (2H, m, H-4e, 4e′), 1.75–1.86 (1H, m, H-3e), 1.76–1.90 (1H, m, H-8′), 1.76–1.87 (1H, m, H-3e′), 1.79–1.93 (1H, m, H-5′), 2.10–2.26 (1H, m, H-5), 2.17–2.27 (1H, m, H-6e), 2.65–2.75 (1H, m, H-6e′), 3.47–3.53 (1H, m, H-1), 3.99–4.05 (1H, m, H-1′).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 20.60 (C-9′), 20.79 (C-9), 21.31 (C-10′), 21.65 (C-10), 22.01 (C-7′), 22.82 (C-7), 25.79 (C-3′), 26.48 (C-3), 26.97 (C-5′), 27.66 (C-5), 29.55 (C-8′), 30.16 (C-8), 34.93 (C-4′), 35.09 (C-4), 36.77 (C-6′), 43.56 (C-6), 48.44 (C-2′), 49.11 (C-2), 52.15 (C-1′), 63.82 (C-1). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Isolated partially. Overall yield of diastereomers 85%.

Second diastereomer of [(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (5b), $[\alpha]_D^{22}$ +176.00° (*c* 0.17, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1080.14 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.89–1.09 (2H, m, H-4a, 4a′), 0.89 (3H, d, J = 6.5, Me), 0.92 (3H, d, J = 6.0, Me-7′), 0.93 (3H, d, J = 6.5, Me-10′), 0.94 (3H, d, J = 6.3, Me-10), 0.95–1.16 (1H, m, H-3a), 1.03 (3H, d, J = 6.5, Me-9), 1.10 (3H, d, J = 6.5, Me-9′), 1.20–1.32 (1H, m, H-2′), 1.25–1.38 (1H, m, H-6a′), 1.38–1.50 (1H, m, H-6a), 1.40–1.53 (1H, m, H-2), 1.60–1.75 (1H, m, H-3a′), 1.61–1.75 (1H, m, H-8), 2.10–2.26 (1H, m, H-5), 1.73–1.84 (1H, m, H-4e′), 1.78–1.94 (1H, m, H-5′), 1.80–1.90 (1H, m, H-3e), 1.85–1.96 (1H, m, H-4e), 1.89–2.00 (1H, m, H-3e′), 1.99–2.10 (1H, m, H-6e), 2.02–2.16 (1H, m, H-8′), 2.29–2.40 (1H, m, H-6e′), 3.81–3.88 (1H, m, H-1), 3.95–4.01 (1H, m, H-1′).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 20.26 (C-9), 21.65 (C-10), 22.00 (C-9′), 22.00 (C-10′), 22.15 (C-7′), 22.40 (C-7), 25.72 (C-3′), 26.61 (C-3), 26.69 (C-5′), 27.95 (C-5), 29.04 (C-8′), 30.00 (C-8), 35.05 (C-4′), 35.50 (C-4), 37.97 (C-6′), 42.40 (C-6), 48.56 (C-2′), 49.50 (C-1′), 50.25 (C-2), 64.43 (C-1). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Isolated partially. Overall yield of diastereomers 85%.

First diastereomer of [(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (6a), $[\alpha]_D^{22}$ –77.14° (*c* 0.34, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1080.14 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.79 (3H, d, J = 6.8, Me-9), 0.84 (3H, d, J = 6.7, Me-9′), 0.88–1.05 (12H, m, Me-7, 7′; Me-10, 10′), 0.89–1.5 (2H, m, H-4a, 4a′), 1.05–1.21 (1H, m, H-3a, 3a′), 1.32–1.45 (1H, m, H-2), 1.38–1.52 (1H, m, H-6a), 1.40–1.59 (1H, m, H-8), 1.50–1.70 (1H, m, H-8′), 1.35–1.50 (1H, m, H-6a′), 1.60–1.75 (1H, m, H-2′), 1.69–1.83 (2H, m, H-4e, 4e′), 1.73–1.87 (2H, m, H-3e, 3e′), 2.09–2.22 (1H, m, H-6e′), 2.18–2.43 (2H, m, H-5, 5′), 2.30–2.42 (1H, m, H-6e), 2.86–2.99 (1H, m, H-1), 3.25–3.37 (1H, m, H-1′).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 15.11 (C-9), 15.67 (C-9′), 21.01 (C-10), 21.14 (C-10′), 22.02 (C-7), 22.29 (C-7′), 24.12 (C-3), 24.87 (C-3′), 27.34 (C-5), 27.58 (C-5′), 32.04 (C-6), 32.39 (C-8), 33.70 (C-8′), 33.97 (C-4), 34.37 (C-4′), 42.98 (C-2), 45.89 (C-6′), 48.04 (C-2′), 52.04 (C-1), 66.64 (C-1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Yield 34%.

Second diastereomer of [(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (6b), $[\alpha]_D^{22}$ –10.40° (*c* 0.15, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1080.24 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.79 (3H, d, J = 6.8, Me-9), 0.84 (3H, d, J = 6.7, Me-9′), 0.88–1.05 (12H, m, Me-7, 7′; Me-10, 10′), 0.89–1.5 (2H, m, H-4a, 4a′), 1.05–1.21 (1H, m, H-3a, 3a′), 1.32–1.45 (1H, m, H-2), 1.38–1.52 (1H, m, H-6a), 1.40–1.59 (1H, m, H-8), 1.50–1.70 (1H, m, H-8′), 1.35–1.50 (1H, m, H-6a′), 1.60–1.75 (1H, m, H-2′), 1.69–1.83 (2H, m, H-4e, 4e′), 1.73–1.87 (2H, m, H-3e, 3e′), 2.09–2.22 (1H, m, H-6e′), 2.18–2.43 (2H, m, H-5, 5′), 2.30–2.42 (1H, m, H-6e), 2.86–2.99 (1H, m, H-1), 3.25–3.37 (1H, m, H-1′).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 14.97 (C-9), 15.39 (C-9′), 20.92 (C-10), 21.20 (C-10′), 22.08 (C-7), 22.14 (C-7′), 24.16 (C-3), 24.82 (C-3′), 26.96 (C-5), 27.47 (C-5′), 32.00 (C-6), 33.18 (C-8), 33.79 (C-8′), 34.39 (C-4), 34.39 (C-4′), 44.92 (C-2), 45.44 (C-6′), 47.37 (C-2′), 49.90 (C-1), 66.62 (C-1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Yield 51%.

First diastereomer of [(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (7a), $[\alpha]_D^{22}$ –8.28° (*c* 0.34, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1076.29 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.83 (3H, d, J = 6.9, Me-9′), 0.86–1.05 (15H, m, Me-7, 7′; Me-9; Me-10, 10′), 0.89–1.02 (2H, m, H-4a′), 0.91–1.03 (2H, m, H-4a), 0.98–1.11 (1H, m, H-3a′), 1.06–1.20 (1H, m, H-3a), 1.17–1.29 (1H, m, H-2′), 1.31–1.44 (1H, m, H-2), 1.38–1.62 (1H, m, H-6a′), 1.51–1.67 (1H, m, H-8′), 1.55–1.69 (1H, m, H-8), 1.57–1.74 (1H, m, H-6a), 1.70–1.81 (2H, m, H-4e, 4e′), 1.72–1.85 (1H, m, H-5), 1.75–1.86 (1H, m, H-3e), 1.78–1.87 (1H, m, H-3e′), 2.02–2.13 (1H, m, H-6e′), 2.12–2.24 (1H, m, H-6e), 2.27–2.41 (1H, m, H-5′), 2.81–2.94 (1H, m, H-1′), 3.93–4.01 (1H, m, H-1).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 15.67 (C-9′), 20.35 (C-9), 20.87 (C-10), 20.99 (C-10′), 22.02 (C-7), 22.30 (C-7′), 24.24 (C-3), 26.41 (C-3′), 26.66 (C-5), 27.34 (C-5′), 29.84 (C-8), 32.06 (C-6), 32.43 (C-8′), 34.02 (C-4), 35.02 (C-4′), 42.66 (C-6′), 43.29 (C-2), 48.64 (C-2′), 49.52 (C-1), 66.38 (C-1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Yield 43%.

Second diastereomer of [(1*S*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexyl-(1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexane thiosulfinate] (7b), $[\alpha]_D^{22}$ –56.96° (*c* 0.37, EtOH). IR spectrum (KBr, ν, cm^{-1}): 1077.12 (S=O).

PMR spectrum (300 MHz, $CDCl_3$, δ, ppm, J/Hz): 0.86–1.07 (2H, m, H-4a, 4a′), 0.86–0.95 (15H, m, Me-7; Me-9, 9′; Me-10, 10′), 1.00 (3H, d, J = 6.3, Me-7′), 0.98–1.11 (1H, m, H-3a′), 1.04–1.21 (1H, m, H-3a), 1.13–1.27 (1H, m, H-2′), 1.19–1.33 (1H, m, H-6a), 1.35–1.48 (1H, m, H-8′), 1.41–1.54 (1H, m, H-6a′), 1.44–1.58 (1H, m, H-8), 1.57–1.70 (1H, m, H-2), 1.71–1.84 (2H, m, H-4e, 4e′), 1.71–1.82 (1H, m, H-3e), 1.75–1.85 (1H, m, H-3e′), 1.82–1.99 (1H, m, H-5, 5′), 2.19–2.30 (1H, m, H-6e′), 2.54–2.65 (1H, m, H-6e), 2.99–3.10 (1H, m, H-1′), 3.93–4.00 (1H, m, H-1).

^{13}C NMR spectrum (75 MHz, $CDCl_3$, δ, ppm): 15.30 (C-9′), 20.44 (C-9), 20.72 (C-10), 20.86 (C-10′), 21.96 (C-7), 22.13 (C-7′), 24.12 (C-3), 26.38 (C-3′), 26.64 (C-5), 27.11 (C-5′), 30.08 (C-8), 32.18 (C-6), 33.19 (C-8′), 34.38 (C-4), 34.97 (C-4′), 43.78 (C-6′), 45.23 (C-2), 49.09 (C-2′), 51.58 (C-1), 67.33 (C-1′). Assignments were made using ^1H–^1H COSY, ^1H–^1H NOESY, and HSQC. $C_{20}H_{38}S_2O$. Yield 46%.

ACKNOWLEDGMENT

The work was supported by the Federal Agency for Science and Innovation under the Federal Targeted Program "Scientific and Educational Staff of Innovation Russia" (State Contract No. 02.740.11.0081).

REFERENCES

1. M. S. Kharash, W. Nudenberg, and T. H. Meltzer, *J. Org. Chem.*, **18**, 1233 (1953).
2. M. Mellah, A. Voituriez, and E. Shultz, *Chem. Rev.*, **107**, 5133 (2007).
3. S. Oae, *Chemistry of Organic Sulfur Compounds* [in Russian], Khimiya, Moscow, 1975.
4. C. Shen, H. Xiao, and K. L. Parkin, *J. Agric. Food Chem.*, **50**, 2644 (2002).
5. W. H. Briggs, H. Xiao, K. L. Parkin, C. Shen, and I. L. Goldman, *J. Agric. Food Chem.*, **48**, 5731 (2000).
6. V. M. Potapov and S. V. Ponomarev (eds.), *Organicum. Training on Organic Chemistry* [in Russian], Mir, Moscow, Vol. 2, 1979, p. 20.
7. A. V. Timshina, S. A. Rubtsova, M. I. Kodess, E. G. Matochkina, P. A. Slepukhin, and A. V. Kuchin, *Zh. Org. Khim.*, **7**, 1053 (2008).
8. S. R. Wilson and P. Caldera, *J. Org. Chem.*, **27**, 3319 (1982).
9. Yu. A. Pentin and L. V. Vilkov, *Physical Research Methods in Chemistry* [in Russian], Mir, Moscow, 2006.