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Synthesis of the Four Stereoisomers of 3,12-Dimethylheptacosane, (Z)-9-Pentacosene and (Z)-9-Heptacosene, the Cuticular Hydrocarbons of the Ant, Diacamma sp.

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Synthesis of the Four Stereoisomers of 3,12-Dimethylheptacosane, (*Z*)-9-Pentacosene and (*Z*)-9-Heptacosene, the Cuticular Hydrocarbons of the Ant, *Diacamma* sp.†

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All of the four stereoisomers of 3,12-dimethylheptacosane were synthesized from the enantiomers of citronellal. (*Z*)-9-Pentacosene and (*Z*)-9-heptacosene were also synthesized. These hydrocarbons are the characteristic components of the cuticular hydrocarbons of the queen of the ant, *Diacamma* sp..

Key words: (*Z*)-alkene; cuticular hydrocarbon; *Diacamma* sp.; dimethyl-branched alkane; queen ant

The cuticular hydrocarbons of social insects such as honeybees and ants are known to be important in their species, colony and queen recognition.[1] A GC-MS analysis by Yamaoka and his co-workers identified the hydrocarbons shown in Fig. 1 as the characteristic components of the cuticular hydrocarbons of the queen ant of *Diacamma* sp. (Togé-ôhariari in Japanese), and suggested them to be possible queen recognition substances.[2] To verify this possibility, however, substantial amounts of these hydrocarbons must be available for a bioassay. At the request of Yamaoka, we initiated our project to synthesize all of the hydrocarbons shown in Fig. 1, and have already published our synthesis of the enantiomers of **A**, **B**, **C**, **D** and **E**.[3] In this paper, we report the synthesis of the remaining hydrocarbons, *i.e.*, all of the four stereoisomers of 3,12-dimethylheptacosane (**1**), (*Z*)-9-pentacosene (**2**) and (Z)-9-heptacosene (**3**).

The retrosynthetic analysis of (3*R*,12*S*)-3,12-dimethylheptacosane (**1**) is shown in Scheme 1. The carbon skeleton of **1** can be constructed by the alkylation of alkyne (*R*)-**F** with iodide (*S*)-**G**. Alkyne **F** is to be derived from (*R*)-citronellal (**4**), while iodide **G** can be prepared from (S)-citronellal (**4**). The enantiomers of citronellal (96–97% *e.e.*) are commercially available.

Scheme 2 summarizes the synthesis of alkyne (*R*)-**A** (=**8**). According to the known method,[4] (*S*)-citronellal (**4**, 96.0% *e.e.*) was converted to (*R*)-4-methyl-1-hexanol (**5**), whose tosylate (*R*)-**6** was treated with sodium iodide to give iodide (*R*)-**7**. Coupling of (*R*)-**7** with lithium acetylide afforded (*R*)-**8**. Similarly, (*R*)-citronellal (**4**, 97.2% *e.e.*) was converted to (*S*)-**8** *via* (*S*)-**5**, **6**, and **7**. Another building block, (*S*)-**B** (=**14**), was then prepared from (*R*)-citronellal (**4**) as shown in Scheme 3. The addition of tridecylmagnesium bromide to (*R*)-**4** gave alcohol **9**.

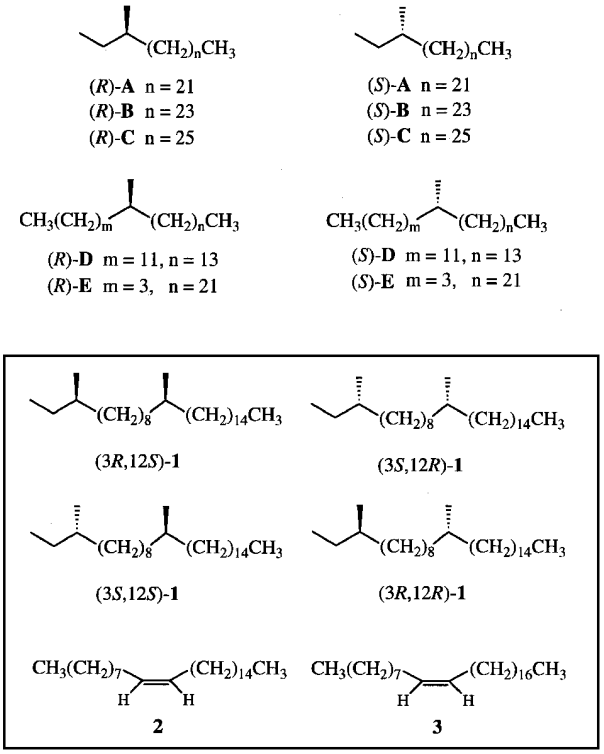

Fig. 1. Structures of the Cuticular Hydrocarbons of the Ant, *Dicamma* sp.

† Pheromone Synthesis, Part 215. For Part 214, see Shibata, C., Furukawa, A., and Mori, K., *Biosci. Biotechnol. Biochem.*, **66**, 582–587 (2002)

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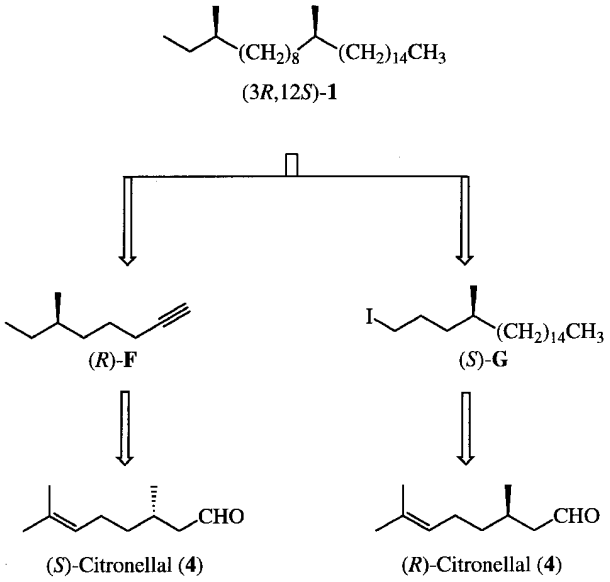
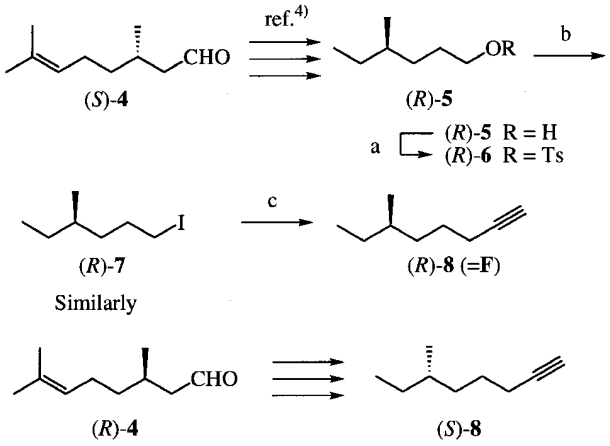
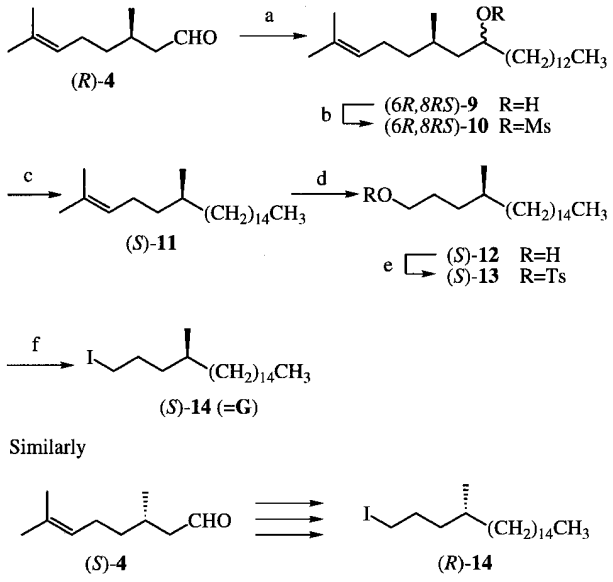


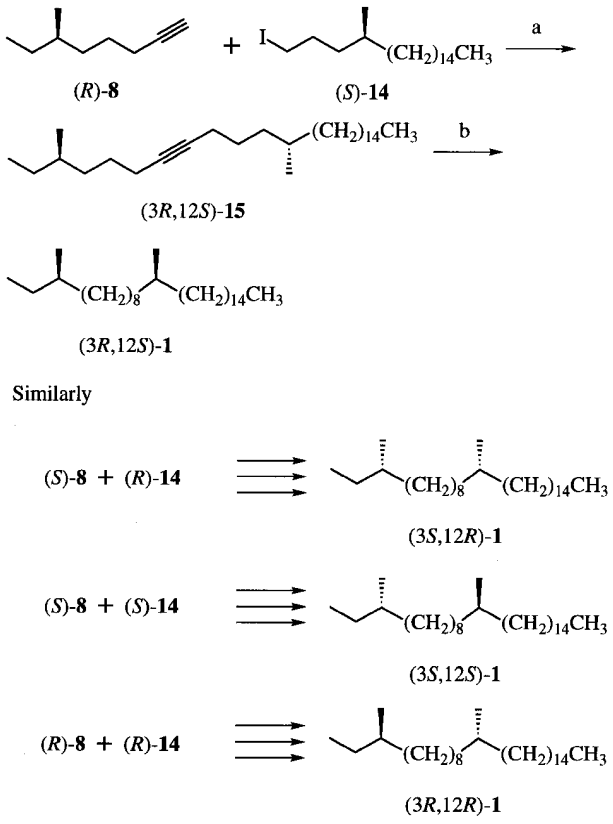
Scheme 1. Retrosynthetic Analysis of (3*R*, 12*S*)-**1**.



Scheme 2. Synthesis of the Enantiomers of **8**.
Reagents: (a) TsCl, C_5H_5N, CH_2Cl_2. (b) NaI, DMF, Me_2CO (81%, 2 steps). (c) $LiC{\equiv}CH \cdot H_2N(CH_2)_2NH_2$, DMSO (60%).



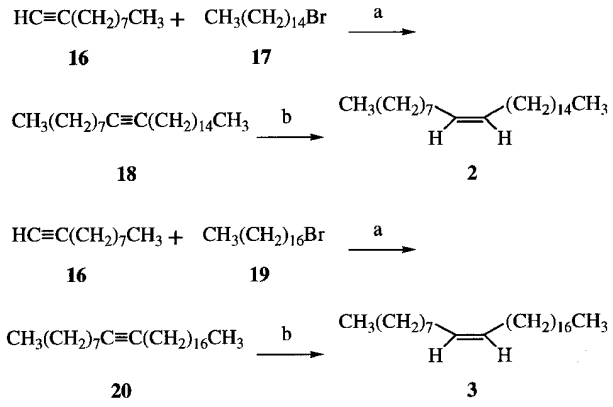
Scheme 3. Synthesis of the Enantiomers of **14**.
Reagents: (a) $CH_3(CH_2)_{12}MgBr$, THF (97%). (b) MsCl, C_5H_5N, CH_2Cl_2. (c) $LiB(C_2H_5)_3H$, THF (99%, 2 steps). (d) 1) O_3, hexane, MeOH, CH_2Cl_2 (1:2:1). 2) $NaBH_4$ (65%, 2 steps). (e) TsCl, C_5H_5N, CH_2Cl_2. (f) NaI, DMF, Me_2CO (88%, 2 steps).



Scheme 4. Synthesis of the Stereoisomers of **1**.
Reagents: (a) **8** + *n*-BuLi, THF, HMPA; then **14** (88%). (b) H_2, PtO_2, hexane (99%).

Corresponding mesylate **10** was reduced with lithium triethylborohydride (Super-Hydride®) to furnish alkene (*S*)-**11**. Ozonolysis of **11** and subsequent reductive workup with sodium borohydride gave alcohol (*S*)-**12**. Corresponding tosylate (*S*)-**13** yielded iodide (*S*)-**14** (=**B**) upon the Finkelstein reaction with sodium iodide. Similarly, (*R*)-**14** was prepared from (*S*)-citronellal (**4**).

Finally, the two building blocks, **8** and **14**, were coupled and further manipulated as summarized in Scheme 4 to give target hydrocarbon **1**. Alkylation of alkyne (*R*)-**8** with iodide (*S*)-**14** furnished new alkyne (3*R*,12*S*)-**15**, which was hydrogenated over Adams' platinum oxide to give (3*R*,12*S*)-(−)-**1** as a low-melting-point solid. The overall yield of (3*R*,12*S*)-**1** based on citronellal (**4**) was 42% *via* (*R*)-**5** (5 steps) or 48% *via* (*R*)-**9** (9 steps). Similarly, the remaining



Scheme 5. Synthesis of **2** and **3**.
Reagents: (a) **10** + *n*-BuLi, THF, HMPA; then **17** or **19** (71% for **18**; 87% for **20**). (b) H_2, 5% Pd-$BaSO_4$, quinoline, hexane (73% for **2**; 78% for **3**).

three isomers, (3*S*,12*R*)-(+)-**1**, (3*S*,12*S*)-(+)-**1** and (3*R*,12*R*)-(−)-**1**, were also synthesized by employing (*R*)- or (*S*)-**8** and (*R*)- or (*S*)-**14**. The IR, NMR and mass spectra of these four stereoisomers of **1** supported their structures. The signs and magnitudes of the specific rotation values of these four isomers indicate that the chirality at C-3 of **1** contributed greatly to determining their chiroptical properties.

Scheme 5 shows the synthesis of (*Z*)-9-pentacosene (**2**) and (*Z*)-9-heptacosene (**3**). Alkylation of 1-decyne (**16**) with pentadecyl bromide (**17**) furnished **18**, whose semi-hydrogenation gave **2** in a 52% yield based on **17** (2 steps). Similarly, alkylation of **16** with heptadecyl bromide (**19**) afforded **20**, which furnished **3** in a 68% overall yield based on **19** (2 steps).

In conclusion, the three cuticular hydrocarbons, **1**, **2** and **3**, characteristic of the ant queen of *Diacamma* sp. were synthesized. In the case of dimethyl-branched hydrocarbon **1**, all of its four stereoisomers were also prepared. These six hydrocarbons, together with ten previous samples will be bioassayed by Prof. Yamaoka. This biological study will hopefully clarify the chemical basis of queen recognition in *Diacamma* sp.

Experimental

Boiling point (bp) data are uncorrected. Melting point (mp) data were measured with a Yanaco MP-S3 instrument and are uncorrected. IR data were measured with Jasco A-102 and Jasco FT/IR-410 spectrometers. ^{1}H-NMR data were measured with Jeol JNM-EX90A (90 MHz), Jeol JNM-LA400 (400 MHz) and Jeol JNM-LA500 (500 MHz) spectrometers (TMS at $\delta_H = 0.00$ or $CHCl_3$ at $\delta_H = 7.26$ was used as the internal standard). Optical rotation data were measured with a Jasco DIP-1000 polarimeter, and MS data were measured with a Jeol JMS-AX 505 HA spectrometer. Refractive index (n_D) data were measured with an Atago DMT-1 refractometer.

(R)-4-Methylhexyl tosylate [(R)-6]. To a stirred and ice-cooled solution of (*R*)-**5** (15.0 g, 129 mmol) in dichloromethane (250 ml) and dry pyridine (30 ml) was added *p*-toluenesulfonyl chloride (24.6 g, 155 mmol) at 0°C. The solution was stirred for 12 h at 4°C. It was then poured into water, and extracted with Et_2O. The ethereal extract was successively washed with water, 1 M HCl, a saturated aqueous $NaHCO_3$ solution and brine, dried with $MgSO_4$, and concentrated *in vacuo* to give 35.1 g (quant.) of crude (*R*)-**6**. IR ν_{max} (film) cm^{-1}: 1600 (m, Ar), 1500 (w, Ar), 1360 (s, SO_2), 1190 (s, SO_2), 1180 (s), 965 (m), 920 (m), 780 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.54–0.94 (6 H, m, 6-H_3, 4-Me), 1.01–1.86 (7 H, m, 4-H, 2-, 3-, 5-H_2), 2.45 (3 H, s, Ar-CH_3), 4.01 (2 H, t, J = 7.2 Hz, 1-H), 7.34 (2 H, d, J = 8.3 Hz, Ar), 7.80 (2 H, d, J = 8.3 Hz, Ar). This compound was employed in the next step without further purification.

(S)-4-Methylhexyl tosylate [(S)-6]. In the same manner as that just described, (*S*)-**5** (10.5 g, 90.3 mmol) was converted into 24.4 g (quant.) of (*S*)-**6** as a colorless oil. Its IR and ^{1}H-NMR spectra were identical with those of (*R*)-**6**. This compound was employed in the next step without further purification.

(R)-1-Iodo-4-methylhexane [(R)-7]. To a solution of crude (*R*)-**6** (*ca.* 35 g) in dry acetone (300 ml) and DMF (80 ml) was added sodium iodide (25.1 g, 168 mmol) at room temperature. The mixture was stirred and heated under reflux for 7 h. To this mixture was added a saturated aqueous $Na_2S_2O_3$ solution, and acetone was removed *in vacuo*. The residue was poured into water and extracted with Et_2O. The ethereal extract was successively washed with water and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (100 g, hexane) and distilled to give 23.7 g [2 steps, 81% based on (*R*)-**5**] of (*R*)-**7** as a colorless oil. Bp 105–107°C at 40 Torr. n_D^{24} 1.4981. $[\alpha]_D^{24}$ −11.1 (*c* 1.05, hexane). IR ν_{max} (film) cm^{-1}: 2960 (s), 2870 (s), 1460 (s), 1175 (s). NMR δ_H (90 MHz, $CDCl_3$): 0.62–1.01 (6 H, m, 4-Me, 6-H_3), 1.06–1.62 (5 H, m, 4-H, 3-, 5-H_2) 1.62–2.00 (2 H, m, 2-H_2), 3.18 (2 H, t, J = 6.8 Hz, 1-H_2). HRMS m/z (M^+): calcd. for $C_7H_{15}I$, 226.0218; found, 226.0218.
Due to the volatility of **7**, no satisfactory combustion analytical data could be obtained.

(S)-1-Iodo-4-methylhexane [(S)-7]. In the same manner as that just described, (*S*)-**6** (*ca.* 24 g) was converted into 16.2 g [2 steps, 80% based on (*S*)-**5**] of (*S*)-**7** as a colorless oil. Bp 98–99°C at 42 Torr. n_D^{21} 1.4900. $[\alpha]_D^{24}$ +10.6 (*c* 1.00, hexane). Its IR and ^{1}H-

NMR spectra were identical with those of (*R*)-**6**. HRMS *m/z* (M^+): calcd. for $C_7H_{15}I$, 226.0218; found, 226.0221.

(R)-6-Methyl-1-octyne [(R)-8]. To a stirred and ice-cooled solution of (*R*)-**7** (23.2 g, 105 mmol) in dry DMSO (200 ml) was added a lithium acetylide ethylenediamine complex (21.4 g, 209 mmol) at 10°C under argon. The mixture was stirred for 30 min at 10°C and was then allowed to warm to room temperature over 12 h. The reaction was quenched with water, and the mixture was extracted with hexane. The organic phase was successively washed with water and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residure was purified by distillation to give 7.72 g (60%) of (*R*)-**8** as a colorless oil. Bp 118–120°C. n_D^{21} 1.4550. $[\alpha]_D^{26}$ −12.6 (*c* 1.01, hexane). IR ν_{max} (film) cm^{-1}: 3315 (s) 2120 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.60–1.00 (6 H, m, 6-Me, 8-H_3), 1.00–1.70 (7 H, m, 6-H, 4-, 5-, 7-H_2), 1.94 (1 H, t, J = 2.7 Hz, 1-H), 2.00–2.26 (2 H, m, 3-H_2). HRMS *m/z* (M^+): calcd. for C_9H_{16}, 124.1252; found, 124.1258. Due to the volatility of **8**, no satisfactory combustion analytical data could be obtained.

(S)-6-Methyl-1-octyne [(S)-8]. In the same manner as that just described, (*S*)-**7** (16.1 g, 71.4 mmol) was converted into 3.71 g (42%) of (*S*)-**8** as a colorless oil. Bp 115–117°C. n_D^{21} 1.4553. $[\alpha]_D^{26}$ +12.7 (*c* 1.05, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (*R*)-**8**. HRMS *m/z* (M^+): calcd. for C_9H_{16}, 124.1252; found, 124.1257.

(6R,8RS)-2,6-Dimethyl-2-henicosen-8-ol [(R)-9]. To a stirred and ice-cooled solution of (*R*)-**4** (594 mg, 3.80 mmol) in dry THF (5 ml) was added a solution of the Grignard reagent prepared from 1-bromotridecane (4.00 g, 15.20 mmol) and magnesium (406 mg, 16.72 mmol) in THF (15 ml) at 0°C under argon. The mixture was allowed to warm to room temperature over 4 h. The reaction was then quenched with a saturated aqueous NH_4Cl solution, and the mixture was extracted with Et_2O. The organic phase was successively washed with water, a saturated aqueous NH_4Cl solution and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (30 g; hexane/ethyl acetate, 30:1) to give 1.19 g (97%) of (*R*)-**9** as a colorless solid. Mp *ca.* 25°C. $[\alpha]_D^{22}$ −2.9 (*c* 1.10, hexane). IR ν_{max} (KBr) cm^{-1}: 3350 (s, O-H). NMR δ_H (90 MHz, $CDCl_3$): 0.85–0.95 (6 H, m, 6-Me, 21-H_3), 1.15–1.53 (30 H, m, 6-H, 5-, 7-, 9~20-H_2, 8-OH), 1.60 (3 H, br.s, CH_3-C=C), 1.69 (3 H, br.s, CH_3-C=C), 1.85–2.07 (2 H, br.q, 4-H_2), 3.65 (1 H, br.m, 8-H), 5.10 (1 H, br.t, 3-H). *Anal.* Found: C, 81.63; H, 13.82%. Calcd. for $C_{23}H_{46}O$: C, 81.58; H, 13.69%.

(6S,8RS)-2,6-Dimethyl-2-henicosen-8-ol [(S)-9]. In the same manner as that just described, (*S*)-**4** (2.00 g, 13.3 mmol) was converted into 3.37 g (79%) of (*S*)-**9** as a colorless solid. Mp *ca.* 25°C. $[\alpha]_D^{22}$ +2.5 (*c* 1.07, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (*R*)-**9**. *Anal.* Found: C, 81.65; H, 13.94%. Calcd. for $C_{23}H_{46}O$: C, 81.58; H, 13.69%.

(6R,8RS)-8-Methanesulfonyloxy-2,6-dimethyl-2-henicosene [(R)-10]. To a stirred and ice-cooled solution of (*R*)-**9** (3.00 g, 9.29 mmol) in dichloromethane (100 ml) and dry pyridine (10 ml) was added methanesulfonyl chloride (1.43 ml, 18.5 mmol) at 0°C. After stirring for 12 h at 4°C, the mixture was poured into water and extracted with hexane. The organic phase was successively washed with 0.5 M HCl, water, a saturated aqueous $NaHCO_3$ solution and brine, dried with $MgSO_4$, and concentrated *in vacuo* to give 3.73 g (quant.) of crude (*R*)-**10**. IR ν_{max} (film) cm^{-1}: 1360 (s, SO_2), 1185 (s, SO_2), 910 (s). NMR δ_H (90 MHz, $CDCl_3$): 0.72–1.00 (6 H, m, 6-Me, 21-H_3), 1.10–1.40 (29 H, m, 6-H, 5-, 7-, 9~20-H_2), 1.61 (3 H, br.s, CH_3-C=C), 1.68 (3 H, br.s, CH_3-C=C), 1.80–2.18 (2 H, m, 4-H_2), 2.99 (3 H, s, CH_3SO_2), 4.60–4.80 (1 H, br.m, 8-H), 4.95–5.20 (1 H, br.m, 3-H). This compound was employed in the next step without further purification.

(6S,8RS)-8-Methanesulfonyloxy-2,6-dimethyl-2-henicosene [(S)-10]. In the same manner as that just described, (*S*)-**9** (3.30 g, 10.2 mmol) was converted into 4.10 g (quant.) of crude (*S*)-**10**. Its IR and ^{1}H-NMR spectra were identical with those of (*R*)-**10**. This compound was employed in the next step without further purification.

(S)-2,6-Dimethyl-2-henicosene [(S)-11]. To a solution of crude (*R*)-**10** (*ca.* 3.7 g) in dry THF (10 ml) was added Super-Hydride® (a 1.0 M solution in THF, 180 ml, 180 mmol) at 0°C under argon. After stirring for 18 h at room temperature, the mixture was poured into water and extracted with hexane. The organic phase was successively washed with a saturated aqueous NH_4Cl solution, water, a saturated aqueous $NaHCO_3$ solution and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (60 g; hexane) to give 2.8 g [2 steps, 99% based on (*R*)-**9**] of (*S*)-**11** as a colorless oil. n_D^{23} 1.4564. $[\alpha]_D^{22}$ −2.0 (*c* 1.10, hexane). IR ν_{max} (film) cm^{-1}: 1465 (m), 1375 (m), 830 (w), 720 (m, CH_2). NMR δ_H (90 MHz, $CDCl_3$): 0.75–1.00 (6 H, m, 6-Me, 21-H_3), 1.05–1.18 (31 H, m, 6-H, 5-, 7-, 8-, 9-, 10-, 11-, 12-, 13-, 14-, 15-, 16-, 17-, 18-, 19-, 20-H_2), 1.60 (3 H, br.s, CH_3−C=C), 1.69 (3 H, br.s, CH_3−C=C), 1.85–2.05 (2 H, br.t, 4-H_2), 5.10 (1 H, br.t, 3-H). *Anal.* Found: C, 85.61; H, 14.52%. Calcd. for $C_{23}H_{46}$: C, 85.63; H, 14.37%.

(R)-2,6-Dimethyl-2-henicosene [(R)-11]. In the same manner as that just described, (*S*)-**10** (*ca.* 4.0 g) was converted into 3.9 g [2 steps, 98% based on (*S*)-**9**] of (*R*)-**11** as a colorless oil. n_{24}^{D} 1.4560. $[\alpha]_D^{24}$ +1.9 (*c* 0.99, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (*S*)-**11**. *Anal.* Found: C, 85.32; H, 14.64%. Calcd. for $C_{23}H_{46}$: C, 85.63; H, 14.37%.

(S)-4-Methylnonadecan-1-ol [(S)-12]. Ozone was bubbled into a stirred solution of (*S*)-**11** (983 mg, 3.25 mmol) in methanol (15 ml), dichloromethane (30 ml) and hexane (15 ml) for 1.5 h at −45°C. After flashing off the excess O_3 with O_2 gas, to the stirred mixture was slowly added $NaBH_4$ (540 mg, 3.57 mmol) at −45°C. The mixture was allowed to warm to 0°C over 6 h before being quenched with 1.0 M HCl and extracted with Et_2O. The organic phase was successively washed with water, a saturated aqueous $NaHCO_3$ solution and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (50 g; hexane/ethyl acetate, 30:1) to give 604 mg (65%) of (*S*)-**12** as a colorless solid. Mp *ca.* 28–30°C. $[\alpha]_D^{20}$ −1.1 (*c* 0.50, hexane). IR ν_{max} (film) cm^{-1}: 3350 (br.m, O-H), 1060 (br.m, C-O). NMR δ_H (90 MHz, $CDCl_3$): 0.78–1.00 (6 H, m, 4-Me, 19-H_3), 1.00–1.80 (34 H, m, 4-H, 2-, 3-, 5∼18-H_2, 1-OH), 3.62 (2 H, t, J=6.5 Hz, 1-H_2). *Anal.* Found: C, 80.26; H, 14.24%. Calcd. for $C_{20}H_{42}O$: C, 80.46; H, 14.18%.

(R)-4-Methylnonadecan-1-ol [(R)-12]. In the same manner as that just described, (*R*)-**11** (1.79 g, 5.85 mmol) was converted into 688 mg (40%) of (*R*)-**12** as a colorless solid. Mp *ca.* 28–30°C. $[\alpha]_D^{20}$ +1.4 (*c* 1.15, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (*R*)-**12**. *Anal.* Found: C, 80.66; H, 14.30%. Calcd. for $C_{20}H_{42}O$: C, 80.46; H, 14.18%.

(S)-4-Methylnonadecyl tosylate [(S)-13]. To a stirred and ice-cooled solution of (*S*)-**12** (1.00 g, 3.47 mmol) in dichloromethane (10 ml) and dry pyridine (2 ml) was added *p*-toluenesulfonyl chloride (728 mg, 3.81 mmol) at 0°C. The solution was stirred for 12 h at 4°C, before being poured into water and extracted with diethyl ether. The ethereal extract was successively washed with water, 1 M HCl, a saturated aqueous $NaHCO_3$ solution and brine, dried with $MgSO_4$, and concentrated *in vacuo* to give 1.64 g (quant.) of crude (*S*)-**13**. IR ν_{max} (film) cm^{-1}: 1590 (m, Ar), 1480 (m, Ar), 1365 (s, SO_2), 1190 (s, SO_2), 1180 (s), 965 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.70–0.90 (6 H, m, 4-Me, 19-H_3), 1.10–1.60 (33 H, m, 4-H, 2-, 3-, 5∼18-H_2), 2.45 (3 H, s, Ar-CH_3), 4.07 (2 H, t, J=6.4 Hz, 1-H_2), 7.43 (2 H, d, J=8.4 Hz, Ar), 7.79 (2 H, d, J=8.4 Hz, Ar). This compound was employed in the next step without further purification.

(R)-4-Methylnonadecyl tosylate [(R)-13]. In the same manner as that just described, (*R*)-**12** (895 mg, 3.10 mmol) was converted into 1.36 g (quant.) of (*R*)-**13** as a colorless oil. Its IR and ^{1}H-NMR spectra were identical with those of (*S*)-**13**. This compound was employed in the next step without further purification.

(S)-1-Iodo-4-methylnonadecane [(S)-14]. To a solution of crude (*S*)-**13** (*ca.* 1.6 g) in DMF (20 ml) was added sodium iodide (1.04 g, 6.94 mmol). The mixture was stirred and heated under reflux for 7 h. To this mixture was added a saturated aqueous $Na_2S_2O_3$ solution. The residue was poured into water and extracted with Et_2O. The ethereal extract was successively washed with water and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (20 g, hexane) to give 1.19 g [2 steps, 88% based on (*S*)-**12**] of (*S*)-**14** as a colorless oil. n_D^{26} 1.4788. $[\alpha]_D^{26}$ +2.5 (*c* 1.00, hexane). IR ν_{max} (film) cm^{-1}: 2950 (m), 2900 (m), 1470 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.71–1.05 (6 H, m, 4-Me, 19-H_3) 1.05–1.60 (31 H, m, 4-H, 3-, 5∼18-H_2), 1.80–2.02 (2 H, m, 2-H_2), 3.27 (2 H, t, J=6.3 Hz, 1-H_2). *Anal.* Found: C, 58.59; H, 10.29%. Calcd. for $C_{20}H_{41}I$: C, 58.81; H, 10.12%.

(R)-1-Iodo-4-methylnonadecane [(R)-14]. In the same manner as that just described, (*R*)-**13** (1.36 g, 3.32 mmol) was converted into 1.19 g [2 steps, 88% based on (*R*)-**12**] of (**R**)-**14** as a colorless oil. n_D^{22} 1.4776. $[\alpha]_D^{22}$ −2.5 (*c* 0.50, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (*S*)-**14**. *Anal.* Found: C, 59.00; H, 10.25%. Calcd. for $C_{20}H_{41}I$: C, 58.81; H, 10.12%.

(3R,12S)-3,12-Dimethyl-7-heptacosyne [(3R,12S)-15]. To a stirred solution of (*R*)-**8** (508 mg, 4.10 mmol) in dry THF (5 ml) and dry hexamethylphosphoric triamide (HMPA, 1 ml) was added *n*-butyllithium in hexane (1.6 M, 2.5 ml, 3.9 mmol) at −40°C under argon. The solution was stirred at 0°C for 5 h and then cooled to −40°C. A solution of (*S*)-**14** (816 mg, 2.05 mmol) in dry THF (10 ml) was added dropwise to the mixture at −40°C. The mixture was stirred at ambient temperature for 12 h before being poured into a saturated aqueous NH_4Cl solution at 0°C and extracted with hexane. The extract was successively washed with water and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (20 g, hexane) to give 711 mg (88%) of (3*R*,12*S*)-**15** as a colorless oil. n_D^{26} 1.4650. $[\alpha]_D^{20}$ −3.2 (*c* 1.04, hexane). IR ν_{max} (film) cm^{-1}: 2925 (s), 2855 (s), 1460 (s), 1375 (m), 720 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.75–1.00 (12 H, m, 1-H_3, 3-Me, 12-Me, 27-H_3), 1.05–1.35

(40 H, m, 3-H, 12-H, 2-, 4-, 5-, 10-, 11-, 13 ~ 26-H_2), 2.00–2.25 (4 H, m, 6-H_2, 9-H_2). *Anal.* Found: C, 85.81; H, 13.70%. Calcd. for $C_{29}H_{56}$: C, 86.05; H, 13.95%.

(3S,12R)-3,12-Dimethyl-7-heptacosyne [(3S,12R)-15]. In the same manner as that just described, (*S*)-**8** (285 mg, 2.30 mmol) and (*R*)-**14** (608 mg, 1.53 mmol) were converted into 427 mg (70%) of (3*S*,12*R*)-**15**. n_D^{26} 1.4656. $[\alpha]_D^{20}$ +2.8 (*c* 0.97, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (3*R*,12*S*)-**15**. *Anal.* Found: C, 85.85; H, 14.18%. Calcd. for $C_{29}H_{56}$: C, 86.05; H,13.95%.

(3S,12S)-3,12-Dimethyl-7-heptacosyne [(3S,12S)-15]. In the same manner as that just described, (*S*)-**8** (260 mg, 2.09 mmol) and (*S*)-**14** (694 mg, 1.74 mmol) were converted into 406 mg (59%) of (3*S*,12*S*)-**15**. n_D^{20} 1.4678. $[\alpha]_D^{20}$ +6.4 (*c* 0.90, hexane). IR ν_{max} (film) cm^{-1}: 2950 (s), 2900 (s), 1480 (s), 1390 (m), 740 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.69–1.00 (12 H, m, 1-H_3, 3-Me, 12-Me, 27-H_3), 1.05–1.60 (40 H, m, 3-H, 12-H, 2-, 4-, 5-, 10-, 11 ~ 26-H_2), 2.00–2.25 (4 H, m, 6-H_2, 9-H_2). *Anal.* Found: C, 85.82; H, 14.11%. Calcd. for $C_{29}H_{56}$: C, 86.05; H, 13.95%.

(3R,12R)-3,12-Dimethyl-7-heptacosyne [(3R,12R)-15]. In the same manner as that just described, (*R*)-**8** (861 mg, 6.94 mmol) and (*R*)-**14** (1.10 g, 2.78 mmol) were converted into 587 mg (54%) of (3*R*,12*R*)-**15**. n_D^{20} 1.4656. $[\alpha]_D^{20}$ −6.3 (*c* 0.98, hexane). Its IR and ^{1}H-NMR spectra were identical with those of (3*S*,12*S*)-**15**. *Anal.* Found: C, 86.32; H, 14.29%. Calcd. for $C_{29}H_{56}$: C, 86.05; H, 13.95%.

(3R,12S)-3,12-Dimethylheptacosane [(3R,12S)-1]. A solution of (3*R*,12*S*)-**15** (595 mg, 1.50 mmol) in hexane (5 ml) was hydrogenated with hydrogen gas in the presence of platinum oxide (40 mg) at atmospheric pressure. The reaction mixture was then stirred for 12 h at room temperature, before the mixture was filtered, and the filtrate was concentrated *in vacuo*. The residue was chromatographed on silica gel (10 g, hexane) to give 592 mg (99%) of (3*R*,12*S*)-**1** as a colorless solid. Mp *ca.* 26°C. $[\alpha]_D^{21}$ −4.2 (*c* 0.98, hexane). IR ν_{max} (KBr) cm^{-1}: 2960 (s), 2920 (s), 2850 (s), 1465 (s), 1375 (m), 1150 (w), 720 (m). NMR δ_H (500 MHz, $CDCl_3$): 0.70–0.80 (12 H, m, 1-H_3, 3-Me, 12-Me, 27-H_3), 1.03–1.18 (4 H, m, 2-H_2, 26-H_2), 1.20–1.40 (44 H, m, 3-H, 12-H, 4 ~ 11-H_2, 13 ~ 25-H_2). NMR δ_C (125 MHz, $CDCl_3$): 11.4, 14.1, 19.2, 19.7, 22.7, 27.1, 29.4, 29.5, 29.66, 29.70, 29.74, 30.0, 31.9, 32.7, 34.4, 36.7, 37.1. HRMS *m/z* (relative intensity): 408 (M^+, 4.0), 238 (27.0), 197 (23.0), 99 (23.0), 85 (52.0), 71 (72.0), 57 (100), 43 (50.0); calcd. for $C_{29}H_{60}$, 408.4695; found, 408.4689. *Anal.* Found: C, 85.17; H, 14.77%. Calcd. for $C_{29}H_{56}$: C, 85.21; H, 14.79%.

(3S,12R)-3,12-Dimethylheptacosane [(3S,12R)-1]. In the same manner as that just described, (3*S*,12*R*)-**15** (290 mg, 0.730 mmol) was converted into 281 mg (99%) of (3*S*,12*R*)-**1** as a colorless solid. Mp *ca.* 26°C $[\alpha]_D^{21}$ +4.4 (*c* 1.00, hexane). Its IR, ^{1}H-NMR and ^{13}C-NMR spectra were identical with those of (3*R*,12*S*)-**1**. HRMS *m/z* (relative intensity): 408 (M^+, 5.0), 238 (24.0), 197 (20.0), 99 (23.0), 85 (49.0), 71 (68.0), 57 (100), 43 (50.0); calcd. for $C_{29}H_{60}$, 408.4695; found, 408.4708. *Anal.* Found: C, 85.38; H, 14.81%. Calcd. for $C_{29}H_{56}$: C, 85.21; H,14.79%.

(3S,12S)-3,12-Dimethylheptacosane [(3S,12S)-1]. In the same manner as that just described, (3*S*,12*S*)-**15** (180 mg, 0.450 mmol) was converted into 179 mg (99%) of (3*S*,12*S*)-**1** as a colorless oil. n_D^{21} 1.4537. $[\alpha]_D^{26}$ +4.2 (*c* 1.00, hexane). IR ν_{max} (KBr) cm^{-1}: 2925 (s), 2855 (s), 1465 (s), 1370 (m), 720 (m). NMR δ_H (500 MHz, $CDCl_3$): 0.82–0.90 (12 H, m, 1-H_3, 3-Me, 12-Me, 27-H_3), 1.04–1.18 (4 H, m, 2-H_2, 26-H_2), 1.20–1.40 (44 H, m, 3-H, 12-H, 4 ~ 11-H_2, 13 ~ 25-H_2). NMR δ_C (125 MHz, $CDCl_3$): 11.4, 14.1, 19.2, 19.7, 22.7, 27.05, 27.08, 29.3, 29.5, 29.63, 29.67, 29.7, 30.0, 31.9, 32.7, 34.4, 36.6, 37.1. HRMS *m/z* (relative intensity): 408 (M^+, 4.0), 238 (24.0), 197 (20.0), 99 (23.0), 85 (50.0), 71 (68.0), 57 (100), 43 (50.0); calcd. for $C_{29}H_{60}$, 408.4695; found, 408.4681. *Anal.* Found: C, 85.38; H, 14.81%. Calcd. for $C_{29}H_{56}$: C, 85.21; H, 14.79%.

(3R,12R)-3,12-Dimethylheptacosane [(3R,12R)-1]. In the same manner as that just described, (3*R*,12*R*)-**15** (20 mg, 0.050 mmol) was converted into 19.8 mg (99%) of (3*R*,12*R*)-**1** as a colorless oil. n_D^{21} 1.4565. $[\alpha]_D^{26}$ −4.1 (*c* 1.25, hexane). Its IR, ^{1}H-NMR and ^{13}C-NMR spectra were identical with those of (3*S*,12*S*)-**1**. HRMS *m/z* (relative intensity): 408 (M^+, 4.0), 238 (33.0), 197 (25.0), 99 (23.0), 85 (55.0), 71 (75.0), 57 (100), 43 (50.0); calcd. for $C_{29}H_{60}$, 408.4695; found, 408.4697. *Anal.* Found: C, 85.10; H, 14.85%. Calcd. for $C_{29}H_{56}$: C, 85.21; H, 14.79%.

9-Pentacosyne [18]. To a stirred and cooled solution of **16** (1.00 g, 7.23 mmol) in dry THF (10 ml) and HMPA (5 ml) was added *n*-butyllithium in hexane (1.60 M, 4.55 ml, 7.23 mmol) at −40°C under argon. The solution was stirred at −20°C for 2 h and then cooled to −40°C. A solution of **17** (2.01 g, 7.23 mmol) in dry THF (20 ml) was added dropwise to the mixture at −40°C. The mixture was stirred at ambient temperature for 12 h, before being poured into a saturated aqueous NH_4Cl solution at 0°C and extracted with hexane. The extract was successively washed with water and brine, dried with $MgSO_4$, and concentrated *in vacuo*. The residue was chromatographed on silica gel (40 g, hexane) to give 1.82 g (71%) of **18** as a colorless solid. Mp *ca.* 28°C. IR ν_{max} (KBr) cm^{-1}: 2955 (s), 2850 (s), 1470 (s), 715

(m). NMR δ_H (90 MHz, $CDCl_3$): 0.70–1.06 (6 H, m, 1-H_3, 25-H_3), 1.10–1.45 (38 H, m, 2∼7-H_2, 12∼24-H_2), 2.00–2.25 (4 H, m, 8-H_2, 11-H_2). *Anal.* Found: C, 86.17; H, 14.00%. Calcd. for $C_{29}H_{56}$: C, 86.12; H, 13.88%.

(Z)-9-Pentacosene [2]. A solution of **18** (550 mg, 1.58 mmol) and quinoline (0.5 ml) in hexane (5 ml) was treated with hydrogen gas in the presence of 5% Pd-$BaSO_4$ (30 mg) at atmospheric pressure. The mixture was stirred for 2 h at room temperature, before the mixture was filtered, and the filtrate was concentrated *in vacuo*. The residue was chromatographed on silica gel (100 g, hexane) to give 393 mg (73%) of **2** as a colorless oil. n_D^{21} 1.4566. IR ν_{max} (film) cm^{-1}: 2925 (s), 2855 (s), 1455 (s), 720 (m). NMR δ_H (400 MHz, $CDCl_3$): 0.88 (6 H, t, J=6.4 Hz, 1-H_3, 25-H_3), 1.20–1.38 (38 H, m, 2∼7-H_2, 12∼24-H_2), 2.01 (4 H, dt, J=6.6, 5.6 Hz, 8-H_2, 11-H_2), 5.30–5.40 (2 H, m, 9-H, 10-H). NMR δ_C (125 MHz, $CDCl_3$): 14.1, 22.7, 27.2, 29.3, 29.4, 29.52, 29.56, 29.65, 29.70, 29.8, 31.91, 31.92, 129.9. HRMS *m/z* (relative intensity): 350 (M^+, 37.0), 125 (36.0), 111 (60.0), 97 (100), 83 (95.0), 57 (100), 55 (85.0),43 (85.0); calcd. for $C_{25}H_{50}$, 350.3922; found, 350.3913. *Anal.* Found: C, 85.53; H, 14.40%. Calcd. for $C_{29}H_{50}$: C, 85.63; H, 14.37%.

9-Heptacosyne [20]. In the same manner as that described for the conversion of **16** to **18**, **16** (1.04 g, 7.51 mmol) and **19** (2.00 g, 6.26 mmol) were converted into 2.07 g (87%) of **20** as a colorless solid. Mp *ca.* 28°C. IR ν_{max} (KBr) cm^{-1}: 2955 (s), 2850 (s), 1470 (s), 715 (m). NMR δ_H (90 MHz, $CDCl_3$): 0.88 (6 H, t, J= 6.3 Hz, 1-H_3, 27-H_3), 1.08–1.52 (42 H, m, 2∼7-H_2, 12∼26-H_2), 2.00–2.25 (4 H, m, 8-H_2, 11-H_2). *Anal.* Found: C, 85.80; H, 14.08%. Calcd. for $C_{29}H_{56}$: C, 86.09; H, 13.91%.

(Z)-9-Heptacosene [3]. In the same manner as that described for the conversion of **18** to **2**, **20** (1.00 g, 2.65 mmol) was converted into 783 mg (78%) of **3** as a colorless oil. n_D^{21} 1.4652. IR ν_{max} (film) cm^{-1}: 2925 (s), 2855 (s), 1465 (s), 720 (m). NMR δ_H (500 MHz, $CDCl_3$): 0.88 (6 H, t, J=6.7 Hz, 1-H_3, 27-H_3), 1.20–1.38 (42 H, m, 2∼7-H_2, 12∼26-H_2), 2.01 (4 H, dt, J=6.7, 5.8 Hz 8-H_2, 11-H), 5.30–5.40 (2 H, m, 9-H, 10-H). NMR δ_C (125 MHz, $CDCl_3$): 14.1, 22.7, 27.2, 29.32, 29.37, 29.53, 29.57, 29.66, 29.70, 29.78, 31.92, 31.93, 129.9. HRMS *m/z* (relative intensity): 378 (M^+, 37.0), 139 (20.0), 125 (36.0), 111 (60.0), 97 (100), 83 (93.0), 57 (98.0), 55 (76.0), 43 (77.0), 41 (37.5); calcd. for $C_{27}H_{54}$, 378.4226; found, 378.4233. *Anal.* Found: C, 85.52; H, 14.54%. Calcd. for $C_{29}H_{56}$: C, 85.63; H, 14.37%.

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