34. Preparation of Optically Active Cyclohexenones: Chirons for the Lipophilic Moiety of Flowery- and Woody-like Odorant Ketones

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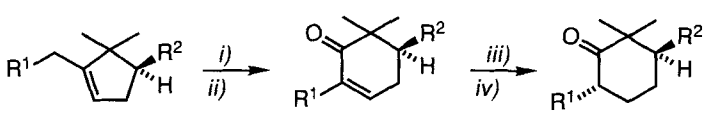
Optically active 2,5,6,6- and 2,4,4,5-tetraalkylcyclohex-2-en-1-ones ((+)-**2a–d** and (–)-**5a–d**), important building blocks for flowery- and woody-like odorants, have been prepared. Compounds (+)-**2a–d** and (–)-**5a–d** were obtained by ozonolysis of the corresponding cyclopentenic precursors, followed by intramolecular aldol condensation. Alternatively, enones (+)-**2a–d** were reduced to the corresponding allylic alcohols and converted to enones (–)-**5a–d** *via* acidic isomerization and oxidation. ^{13}C-NMR assignments are presented.

Introduction. – 2,5,6,6- and 2,4,4,5-Tetraalkylcyclohex-2-en-1-ones are important and characteristic building blocks for the lipophilic part of many fragrances [1] and carotenoids [2]. To our knowledge, despite the tremendous work on this subject [3], only two examples of optically active ketones, (3*R*)-**3a** [4] and (5*R*)-**5c** [5], possessing this substructure, have been reported in the literature[1]). Requiring the optically active cyclohexenones **2** and **5** in both antipodal forms for the preparation and olfactive evaluation of precious flowery and woody natural [14] and synthetic [15] fragrances, we decided to employ the same methodology that we had previously developed for the preparation of campholenal analogues [16]. The appropriately substituted cyclopentenes **1** (*Scheme 1*)

Scheme 1



	R^1	R^2		
(–)-**1a**	H	Me	(+)-**2a**: 68%	(+)-**3a**: 92%
(+)-**1b**	H	Et	(+)-**2b**: 74%	(+)-**3b**: 94%
(–)-**1c**	Me	Me	(+)-**2c**: 70%	(+)-**3c**: 93%
(+)-**1d**	Me	Et	(+)-**2d**: 89%	(+)-**3d**: 79%

i) O_3, MeOH, CH_2Cl_2, –78°; Me_2S; *ii*) TsOH, cyclohexane, reflux; *iii*) H_2, 5% Pd/C, AcOEt; *iv*) NaOEt, EtOH, reflux.

[1]) For racemic material, see: **2c**: [6], **3a**: [7], **3c**: [8], **5a**: [9], **5b**: [10], **6a**: [11], **6b**: [10], **6c**: [12]. For examples of related substructures possessing functionalized substituents, see [13].

and **4** were easily obtained [17] from commercially available (+)- or (−)-α-pinene and (+)- or (−)-α-ethylapopinene[2]).

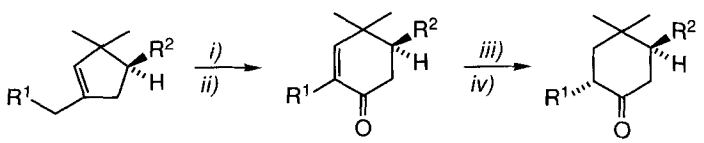
Results and Discussion. – Thus, the olefins (−)-**1a**, **c**[3]) and (+)-**1b**, **d**[3]) were ozonolyzed (*a*) O_3, MeOH, CH_2Cl_2, −78°, *b*) Me_2S) and the crude δ-ketoaldehydes were cyclized (TsOH cat., cyclohexane, reflux) in 68–89% overall yield to cyclohexenones (+)-**2a–d**. Further hydrogenation (H_2, 5% Pd/C, AcOEt) led to (+)-**3a–d** in 79–94% yield.

Contrary to the dextrorotatory properties reported for (3*R*)-**3a**[4]), we observed the opposite sign of rotation for this absolute configuration[5]).

The crude *cis*/*trans*-cyclohexanones **3c**, **d** were epimerized in basic conditions (EtONa, EtOH, reflux) to give mainly the *trans*-isomers (+)-**3c** and (+)-**3d** in a 15:85 and 19:81 *cis*/*trans*-ratio respectively.

Similarly, the olefins (+)-**4a–d** were subjected to ozonolysis, followed by intramolecular aldol condensation, to give cyclohexenones (−)-**5a–d** in 58–78% overall yield

Scheme 2



	R^1	R^2		
(+)-**4a**	H	Me	(−)-**5a:** 58%	(−)-**6a:** 98%
(+)-**4b**	H	Et	(−)-**5b:** 78%	(+)-**6b:** 81%
(+)-**4c**	Me	Me	(−)-**5c:** 71%	(−)-**6c:** 80%
(+)-**4d**	Me	Et	(−)-**5d:** 68%	(+)-**6d:** 86%

i) O_3, MeOH, CH_2Cl_2, −78°; Me_2S; *ii*) TsOH, cyclohexane, reflux; *iii*) H_2, 5% Pd/C, AcOEt; *iv*) EtONa, EtOH, reflux.

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[2]) Derived from commercial (−)-nopol ((1*R*)-6,6-dimethylbicyclo[3.1.1]hept-2-ene-2-ethanol [16]. (+)-Nopol (α_D^{20} = +36.5) was obtained by reduction ($LiAlH_4$, THF, 92% yield) of (+)-(1*S*)-6,6-dimethylbicyclo[3.1.1]hept-2-ene-2-acetic acid ((+)-**7**, *Scheme 3*) [18], readily obtained by addition of metallated (+)-α-pinene (α_D^{20} = +48.5; 95% ee) (BuLi, *t*-BuOK, THF [19]) to CO_2 (THF, −78°; 78% yield). This two-step procedure was found superior in terms of purification in comparison with the direct but non-regioselective addition to formaldehyde [20]. Alternatively, (+)-nopol was also obtained by a *Prins* reaction (HCHO, $ZnCl_2$, 100°; 47% yield [21]) on (+)-β-pinene (92.4% ee).

[3]) (−)-**1a**: α_D^{20} = −5.1, 76% ee; (+)-**1b**: α_D^{20} = +2.9, 80% ee; (−)-**1c**: α_D^{20} = −9.2, 86% ee; (+)-**1d**: α_D^{20} = +2.5, $[\alpha]_D^{20}$ = +3.6 (*c* = 1.0, $CHCl_3$), 90% ee; (+)-**4a**: α_D^{20} = +17.2, 90% ee; (+)-**4b**: α_D^{20} = +27.9, $[\alpha]_D^{20}$ = +46.7 (*c* = 1.8, $CHCl_3$), 90% ee; (+)-**4c**: α_D^{20} = +1.4, 90% ee; (+)-**4d**: α_D^{20} = +30.6, 90% ee [17].

[4]) (3*R*)-**3a**: [4]: $[\alpha]_D^{20}$ = +39.1 (*c* = 0.0043, $CDCl_3$). In our case, we observed for (3*S*)-**3a**: α_D^{20} = +47.6, $[\alpha]_D^{20}$ = +55.8 (*c* = 4.32, $CHCl_3$); $[\alpha]_D^{20}$ = +56.6 (*c* = 0.431, $CHCl_3$); $[\alpha]_D^{20}$ = +55.8 (*c* = 0.043, $CHCl_3$); $[\alpha]_D^{20}$ = +139.5 (*c* = 0.0043, $CHCl_3$, beyond the resolution limits of our polarimeter).

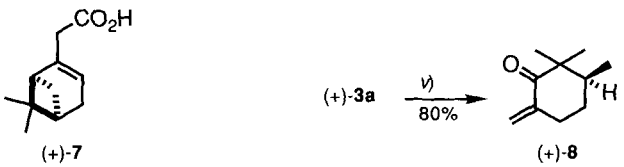
[5]) Starting from (+)-**1a** (α_D^{20} = +5.9, 88% ee), the following antipodes were obtained: (−)-**2a**: α_D^{20} = −68.0; (−)-**3a**: α_D^{20} = −44.15; (−)-**3c**: $[\alpha]_D^{20}$ = −54.7 (*c* = 3.1, $CHCl_3$), obtained by methylation (LDA, THF, MeI, 75% yield) of (−)-**3a**; (−)-**8**: $[\alpha]_D^{20}$ = −10.9 (*c* = 1.4, CCl_4).
Starting from (−)-**4a** (α_D^{20} = −17.6, 92% ee), the following antipodes were obtained: (+)-**5a**: α_D^{20} = +58.2; (+)-**6a**: α_D^{20} = +12.5.

(*Scheme 2*). This synthesis confirms the absolute configuration of (+)-(5*R*)-**5c**[6]), a natural product isolated from iris essential oil [22] and first characterized in 1981 by *Garnero* and *Joulain* [5].

Hydrogenation of (−)-**5a–d** delivered the optically active cyclohexanones **6a–d** in 80–98% yield. The *trans*-isomers **6c, d**[7]) were obtained as *cis*/*trans*-mixtures (12:88 and 21:79, respectively) after epimerization in basic conditions (EtONa, EtOH, reflux).

A modified *Mannich* condensation [25] on (+)-**3a** furnished the α-methylidenecyclohexanone (+)-**8**[5]) in 80% yield (*Scheme 3*). This enone was used immediately for further transformations due to its rapid dimerization.

Scheme 3



v) CF_3CO_2H, (Me)(Ph)NH, $(HCHO)_3$.

Alternatively, cyclohexenones (−)-**5a–d** were also prepared from (+)-**2a–d** by enone transposition [27]. The *cis*-cyclohex-2-en-1-ols (+)-**9a–d**[8]) were stereoselectively obtained by reduction ($LiAlH_4$, Et_2O, 67–98% yield) of (+)-**2a–d** (*Scheme 4*[9])). Acidic isomerization (H_2SO_4 (cat.), H_2O, dioxan, reflux, 71–92% yield), followed by oxidation (PCC, CH_2Cl_2, 74–91% yield) of the resulting mixture, gave preferentially the cyclohexenones (−)-**5a–d** (67–74%, GC) as well as (+)-**2a–d** (24–33%, GC). A chromatographic separation resulted in lower isolated yields of (−)-**5a–d** in comparison with the approach outlined in *Scheme 2*. Cyclohexenones (−)-**5a–d** were stereoselectively reduced ($LiAlH_4$, Et_2O, 95–98% yield) to *cis*-**10a–d** and used as standards for GC/MS comparison of the acidic isomerisation mixture, *cis*/*trans*-**9**/*cis*/*trans*-**10**.

The optical purities of ketones **2a–d**, **3a–d**, **5a–d**, and **6a–d** were determined by ^{1}H-NMR analysis in the presence of Eu(hfbc)$_3$[10]), after the intramolecular aldol condensation, hydrogenation, and acidic isomerization/oxidation steps. In all cases, the optical purity was identical with that of the starting material[3])[5])[6]), proving that racemization does not occur during this sequence.

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[6]) (5*R*)-**5c**: [5]: $[\alpha]_D^{20} = +10.0$ ($c = 0.22$, $CHCl_3$); [22b]: $[\alpha]_D^{20} = +11.0$ ($c = 4.0$, $CHCl_3$). In our case, (−)-**4c** ($\alpha_D^{20} = -1.45$, 92% ee) furnished (+)-(5*R*)-**5c**: $[\alpha]_D^{20} = +65.5$ ($c = 4.8$, $CHCl_3$). The absolute configuration of α-irones depends on the geographical origin of the iris plant [23], the antipode (−)-(5*S*)-**5c** is certainly also a natural product [24].

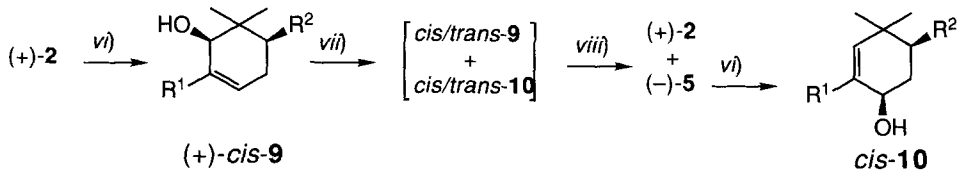
[7]) *cis*/*trans*-Ketone **6c** of undetermined absolute configuration is a natural product found in iris essential oil [5].

[8]) Compound **9c** [3a] [28] of undetermined absolute configuration is a natural product found in the Greek plant *Calamintha nepeta* [29].

[9]) For comparison of diastereoisomeric pairs [26]: *cis*-**9a**, 10.3 Kcal/mol; *trans*-**9a**, 10.1 Kcal/mol; *cis*-**10a**, 9.87 Kcal/mol; *trans*-**10a**, 9.83 Kcal/mol; *cis*-**9c**, 11.3 Kcal/mol; *trans*-**9c**, 10.7 Kcal/mol; *cis*-**10c**, 10.7 Kcal/mol; *trans*-**10c**, 10.4 Kcal/mol.

[10]) Europium (III)tris(3-heptafluorobutyryl)-*d*-camphorate.

Scheme 4



(+)-*cis*-**9** *cis*-**10**

vi) $LiAlH_4$, Et_2O, 0°; *vii*) H_2SO_4 (cat.), H_2O, dioxan, reflux; *viii*) PCC, CH_2Cl_2.

	R^1	R^2	(+)-*cis*-**9**	*cis*-**9**/*trans*-**9**/*cis*-**10**/*trans*-**10**[a])	Yield[b])	(+)-**2**/(−)-**5**[c])	Yield[d])	*cis*-**10**
a	H	Me	89%	20 : 18 : 36 : 27	92%	33 : 67	91 (37%)	(−) 98%
b	H	Et	67%	23 : 13 : 38 : 26	87%	32 : 68	80 (27%)	(+) 95%
c	Me	Me	78%	9 : 19 : 31 : 41	69%	24 : 76	74 (23%)	(−) 97%
d	Me	Et	98%	7 : 20 : 30 : 43	71%	26 : 74	75 (25%)	(+) 98%

[a]) Assigned by comparison with the GC/MS of (+)-*cis*-**9** and *cis*-**10** as well as with the resulting (+)-**2**/(−)-**5** ratio.

[b]) Yield of crude *cis*/*trans*-**9**/*cis*/*trans*-**10**. The reaction was quenched before reaching the thermodynamic equilibrium due to the appearance of dehydrated material after prolonged periods[9]).

[c]) GC Ratio.

[d]) Yield of crude (+)-**2**/(−)-**5** and of purified (−)-**5** in brackets.

This methodology, together with the availability of α-pinene and α-ethylapopinene in both antipodal optically pure forms[11]), allows the preparation of new optically active cyclohexenones. Their further transformations and the olfactive comparison of the resulting antipodes will be soon reported in this journal.

We thank Dr. *K. H. Schulte-Elte* for helpful discussions, the apprentice laboratory of Mr. *B. Egger* for the preparation of (−)-α-ethyl apopinene, Dr. *M. Lindström* for a sample of naturally occurring (+)-β-pinene [33], Drs. *B. Winter* and *A. Boschung* for MM2 calculations, Dr. *P.-A. Blanc* for olfactive evaluations as well as Mrs. *B. Baer*, Miss *C. Cantatore*, Mr. *M. Barthe*, and Mr. *M. Wuest* for their experimental skill.

Experimental Part

General. See [16]. Optical rotations in a 1-cm cell for neat material and a 10-cm cell for solns.

General Procedure for Ozonolysis and Intramolecular Aldol Condensation i) *and* ii). A soln. of the appropriate olefin **1** or **4** (1.45 mol) in CH_2Cl_2 (800 ml) and MeOH (730 ml) was cooled at −78° and a flow of O_3 (18 g/h) was passed through, until no more starting material was detected by GC. The apparatus was purged with N_2, and Me_2S (285 ml) was added dropwise at −20°. The mixture was stirred overnight at 25° and then concentrated. The crude oil was diluted with cyclohexane (400 ml), and TsOH (13 g, 0.068 mol) was added. The mixture was refluxed for 4 h with continuous separation of H_2O. The cold soln. was washed with H_2O, sat. aq. Na_2CO_3 soln., H_2O, and brine, dried (Na_2SO_4), and evaporated. The crude oil was purified by distillation with a 15–25-cm column packed with helices.

General Procedure for Hydrogenation iii). A soln. of the appropriate cyclohexenone (+)-**2** or (−)-**5** (0.32 mol) in AcOEt (500 ml) was hydrogenated at r.t. and ambient pressure over 5 Pd/C (3.0 g). The soln. was filtered through *Celite*, concentrated, and distilled with a 15-cm *Vigreux* column.

[11]) Available by direct low-temperature crystallization [30] or *via* crystallization of a boron adduct [31] [32].

General Procedure for Epimerization iv). A soln. of the appropriate 6-substituted or 2-substituted cyclohexanone **3** or **6** (18 mmol) in EtONa/EtOH (36 ml, 0.05M, 1.8 mmol) was stirred overnight at reflux and then evaporated. Et_2O (50 ml) was added, and the org. phase was washed with H_2O, brine, then dried (Na_2SO_4) and evaporated. The crude oil was purified by distillation.

General Procedure for Reduction vi). To a suspension of $LiAlH_4$ (4.0 g, 0.092 mol) in Et_2O (300 ml) at 0° was added dropwise a soln. of the appropriate enone (+)-**2** or (−)-**5** (0.24 mol) in Et_2O (100 ml). After 1 h at r.t., H_2O (4 ml), 15% aq. NaOH soln. (4 ml), then H_2O (12 ml) were added. After 30 min, the mixture was filtered through *Celite* and evaporated to give a crude oil, purified by distillation.

General Procedure for Isomerisation vii). The appropriate alcohol (+)-**9** (14 mmol) in H_2O (4.2 ml) was diluted with a minimum of dioxan (*ca.* 10 ml) to obtain an homogeneous soln., and one drop of 98% H_2SO_4 was added, followed by a little dioxan (*ca.* 1 ml). The soln. was refluxed and analyzed by GC, until *cis*/*trans*-**10** predominated over *cis*/*trans*-**9**. The cooled mixture was diluted with Et_2O (30 ml) and extracted with H_2O (4 × 10 ml), sat. aq. $NaHCO_3$ soln. (3 × 10 ml), and H_2O (3 × 10 ml), dried (Na_2SO_4) and evaporated to give a crude oil that was used without further purification.

General Procedure for Oxidation viii). To a suspension of pyridinium chlorochromate (3.25 g, 15 mmol) in CH_2Cl_2 (5 ml) was added dropwise a soln. of the appropriate *cis*/*trans*-**9**/*cis*/*trans*-**10** (10 mmol) in CH_2Cl_2 (5 ml). The mixture was stirred for 6 h at r.t., diluted with Et_2O (50 ml), filtered through *Celite*, washed successively with 15% aq. HCl, H_2O, and brine, dried (Na_2SO_4) and evaporated. The crude oil was chromatographed on SiO_2 with cyclohexane/AcOEt 97:3 to separate (+)-**2** from (−)-**5**.

(+)-(5S)-5,6,6-Trimethylcyclohex-2-en-1-one ((+)-**2a**). Obtained in 68% yield from (−)-**1a** following *Procedure i* and *ii*. B.p. 68°/17 Torr. $\alpha_D^{20} = +64.0$. IR: 3020, 2960, 1670, 1635, 1560, 1450, 1390, 1275, 1150, 815. ^{1}H-NMR: 0.98 (*s*, 3 H); 1.00 (*d*, *J* = 7, 3 H); 1.14 (*s*, 3 H); 2.00 (*m*, 1 H); 2.14 (*m*, 1 H); 2.38 (*m*, 1 H); 5.93 (br. *d*, *J* = 9, 1 H); 6.82 (*m*, 1 H). ^{13}C-NMR: *Table 1*. MS: 138 (18, M^+), 95 (5), 68 (100), 55 (18), 39 (12). Saffron, camphor.

Table 1. *^{13}C-NMR Data of Compounds (+)-***2a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(6)[a])	Me(*cis*)–C(6)[a])	R^1	R^2	
(+)-**2a**	H	Me	205.1	128.1	147.5	32.0	38.5	45.3	22.3	18.3		15.4	
(+)-**2b**[b])	H	Et	204.9	128.2	147.3	28.2	45.5	45.6	22.4	19.0		22.0	12.4
(+)-**2c**[b])	Me	Me	204.4	133.8	141.7	31.9	39.0	45.2	22.8	18.4	16.2	15.5	
(+)-**2d**	Me	Et	205.1	133.5	142.3	27.9	45.7	45.4	22.7	19.0	16.5	22.1	12.3

[a]) Relative to R^2.

[b]) 2D Experiments: COSY and C,H correlations.

(+)-(5S)-5-Ethyl-6,6-dimethylcyclohex-2-en-1-one ((+)-**2b**). Obtained in 74% yield from (+)-**1b** following *Procedure i* and *ii*. B.p. 50°/3.7 Torr. $\alpha_D^{20} = +68.1$. IR: 3020, 2970, 1675. ^{1}H-NMR: 0.94 (*t*, *J* = 7, 3 H); 0.98 (*s*, 3 H); 1.16 (*s*, 3 H); 1.20 (*m*, 1 H); 1.65 (*m*, 2 H); 2.08 (*tdd*, *J* = 2, 9, 18, 1 H); 2.53 (*tdd*, *J* = 2, 5, 18); 5.93 (br. *d*, *J* = 9, 1 H); 6.85 (*m*, 1 H). ^{13}C-NMR: *Table 1*. MS: 152 (12, M^+), 84 (42), 69 (67), 68 (100), 55 (10), 41 (19). Metallic, saffron.

(+)-(5S)-2,5,6,6-Tetramethylcyclohex-2-en-1-one ((+)-**2c**). Obtained in 70% yield from (−)-**1c** following *Procedure i* and *ii*. B.p. 92°/25 Torr. $\alpha_D^{20} = +71.0$. $[\alpha]_D^{20} = +79.5$ (*c* = 2.2, $CHCl_3$). IR: 2990, 1680, 1450, 1380, 1200, 1060, 1020. ^{1}H-NMR: 0.95 (*s*, 3 H); 0.97 (*d*, *J* = 7, 3 H); 1.14 (*s*, 3 H); 1.76 (*s*, 3 H); 1.97 (*m*, 1 H); 2.1 (*m*, 1 H); 2.3 (*m*, 1 H); 6.59 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 152 (5, M^+), 82 (100), 54 (15). Bitter almond, saffron.

(+)-(5S)-5-Ethyl-2,6,6-trimethylcyclohex-2-en-1-one ((+)-**2d**). Obtained in 89% yield from (+)-**1d** following *Procedure i* and *ii*. B.p. 64°/2.5 Torr. $\alpha_D^{20} = +82.4$. $[\alpha]_D^{20} = +89.4$ (*c* = 1.9, $CHCl_3$). IR: 2960, 1660, 1450, 1380, 1200, 1030. ^{1}H-NMR: 0.92 (*t*, *J* = 7, 3 H); 0.95 (*s*, 3 H); 1.16 (*s*, 3 H); 1.20 (*m*, 1 H); 1.64 (*m*, 2 H); 1.77 (br. *s*, 3 H); 2.03 (*m*, 1 H); 2.48 (*m*, 1 H); 6.61 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 166 (12, M^+), 82 (100), 54 (17), 41 (19). Turpentine, camphor, saffron.

(+)-(3S)-2,2,3-Trimethylcyclohexan-1-one ((+)-**3a**). Obtained in 92% yield after hydrogenation of (+)-**2a** following *Procedure iii*. B.p. 51°/7.2 Torr. $\alpha_D^{20} = +47.6$[4]). IR: 2960, 2870, 1710, 1450, 1390, 1320, 1260, 1150, 1120, 1020, 940. ^{1}H-NMR: 0.95 (*d*, *J* = 7, 3 H); 1.02 (*s*, 3 H); 1.10 (*s*, 3 H); 1.60 (*m*, 1 H); 1.70 (*m*, 3 H); 1.97 (*m*, 1 H); 2.30 (*m*, 1 H); 2.48 (*m*, 1 H). ^{13}C-NMR: *Table 2*. MS: 140 (36, M^+), 98 (30), 96 (81), 84 (23), 81 (15), 69 (100), 55 (44), 41 (42), 39 (15). Camphor.

Table 2. *^{13}C-NMR Data of Compounds* **3a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(2)[a])	Me(*cis*)–C(2)[a])	R^1	R^2	
(+)-**3a**[b])	H	Me	216.2	48.8	42.4	29.7	25.2	37.8	23.1	19.5		15.7	
(+)-**3b**[b])	H	Et	216.2	49.2	49.9	25.5	25.1	38.0	23.0	20.0		22.4	12.9
(+)-*trans*-**3c**[b])	Me	Me	217.1	48.5	43.1	30.2	35.1	40.0	22.5	19.0	15.0	15.7	
(−)-*cis*-**3c**[b])	Me	Me	217.9	48.7	42.3	28.0	31.2	40.0	26.9	22.2	15.0	15.9	
(+)-*trans*-**3d**[b])	Me	Et	217.3	49.0	50.7	26.3	35.1	40.3	22.4	19.8	15.1	22.9	13.0
(−)-*cis*-**3d**[c])	Me	Et	218.2	[d])	49.0	22.4	30.8	40.0	27.2	21.8	15.1	20.8	12.4

[a]) Relative to R^2.
[b]) 2D Experiments: COSY and C,H correlations.
[c]) Deduced from the hydrogenation mixture before epimerization.
[d]) Not visible.

(+)-(3S)-3-Ethyl-2,2-dimethylcyclohexan-1-one ((+)-**3b**). Obtained in 94% yield after hydrogenation of (+)-**2b** following *Procedure iii*. B.p. 100°/10 Torr. $\alpha_D^{20} = +58.9$. $\alpha_D^{20} = +63.4$ ($c = 1.4$, $CHCl_3$). IR: 2970, 2940, 1705, 1460, 1385, 1310, 1260, 1120, 950. ^{1}H-NMR: 0.92 (*t*, $J = 7$, 3 H); 1.02 (*s*, 3 H); 1.11 (*s*, 3 H); 1.12 (*m*, 1 H); 1.33 (*tt*, $J = 2, 7, 1$ H); 1.45 (*m*, 1 H), 1.58 (*m*, 2 H); 1.90 (*m*, 1 H); 1.98 (*m*, 1 H); 2.30 (*tdd*, $J = 5, 2, 12, 1$ H); 2.50 (*m*, 1 H). ^{13}C-NMR: *Table 2*. MS: 154 (27, $M^{+\cdot}$), 121 (13), 110 (58), 97 (20), 83 (48), 69 (100), 55 (73), 41 (52). Fishy, camphor.

(+)-(3S,6S)-2,2,3,6-Tetramethylcyclohexan-1-one ((+)-**3c**). Obtained in 95% yield after hydrogenation of (+)-**2c** following *Procedure iii* as a 1:1 *cis*/*trans*-mixture. $\alpha_D^{20} = +8.8$. This mixture was epimerized according to *Procedure iv* to give in 93% overall yield a 15:85 *cis*/*trans*-mixture. $[\alpha]_D^{20} = +52.2$ ($c = 1.78$, $CHCl_3$). B.p. 98°/20 Torr. IR: 2940, 1700, 1450, 1370, 1315, 1000. ^{1}H-NMR: 0.95 (*d*, $J = 7$, 3 H); 0.98 (*d*, $J = 7$, 3 H); 1.02 (*s*, 3 H); 1.05 (*s*, 3 H); 1.30 (*m*, 1 H); 1.60 (*m*, 3 H); 2.00 (*m*, 1 H); 2.65 (*m*, 1 H). ^{13}C-NMR: *Table 2*. MS: 154 (28, $M^{+\cdot}$), 112 (22), 96 (100), 84 (41), 69 (98), 55 (40), 41 (28). Camphor, mint.

(+)-(3S,6S)-3-Ethyl-2,2,6-trimethylcyclohexan-1-one ((+)-**3d**). Obtained in 83% yield after hydrogenation of (+)-**2d** following *Procedure iii* as a 43:57 *cis*/*trans*-mixture. $[\alpha]_D^{20} = +36.4$ ($c = 2.5$, $CHCl_3$). This mixture was epimerized according to *Procedure iv* to give in 79% overall yield a 19:81 *cis*/*trans*-mixture. B.p. 80°/1.8 Torr. $[\alpha]_D^{20} = +72.4$ ($c = 1.15$, $CHCl_3$). IR: 2960, 2940, 2870, 1700, 1460, 1380. ^{1}H-NMR: 0.92 (*t*, $J = 7$, 3 H); 0.98 (*d*, $J = 7$, 3 H); 1.01 (*s*, 3 H); 1.08 (*s*, 3 H); 1.10–1.60 (*m*, 5 H); 1.87 (*m*, 1 H); 2.03 (*m*, 1 H); 2.66 (*m*, 1 H). ^{13}C-NMR: *Table 2*. MS: 168 (23, $M^{+\cdot}$), 125 (15), 110 (73), 98 (20), 83 (36), 69 (100), 55 (61), 41 (54). Earthy, humus.

(−)-(5S)-4,4,5-Trimethylcyclohex-2-en-1-one ((−)-**5a**). Obtained in 58% yield from (+)-**4a** following *Procedure i* and *ii*. B.p. 50°/1.3 Torr; 86°/14 Torr. $\alpha_D^{20} = -45.6$, $[\alpha]_D^{20} = -47.4$ ($c = 0.35$, $CHCl_3$). IR: 2960, 2860, 1670, 1460, 1370, 1280, 1200, 1120, 780. ^{1}H-NMR: 0.98 (*d*, $J = 7$, 3 H); 1.01 (*s*, 3 H); 1.16 (*s*, 3 H); 2.03 (*m*, 1 H); 2.30 (*m*, 2 H); 5.84 (*d*, $J = 9$, 1 H); 6.66 (*d*, $J = 9$, 1 H). ^{13}C-NMR: *Table 3*. MS: 138 (14, $M^{+\cdot}$), 123 (8), 96 (100), 81 (67), 69 (34), 67 (40), 41 (26). Camphor.

Table 3. *^{13}C-NMR Data of Compounds (−)-***5a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(4)[a])	Me(*cis*)–C(4)[a])	R^1	R^2	
(−)-**5a**	H	Me	200.2	126.6	160.9	36.0	38.3	42.4	27.6	20.1		15.8	
(−)-**5b**	H	Et	200.4	126.4	161.3	36.3	45.5	38.7	27.7	20.2		22.7	12.1
(−)-**5c**[b])	Me	Me	200.2	132.4	156.2	36.2	38.7	42.5	28.1	20.2	15.6	15.8	
(−)-**5d**	Me	Et	200.4	132.3	156.6	36.4	45.8	38.8	28.1	20.4	15.6	22.7	12.1

[a]) Relative to R^2.
[b]) 2D Experiments: COSY and C,H correlations.

(−)-(5S)-5-Ethyl-4,4-dimethylcyclohex-2-en-1-one ((−)-**5b**). Obtained in 78% yield from (+)-**4b** following *Procedure i* and *ii*. B.p. 90°/5 Torr. $\alpha_D^{20} = -7.7$; $[\alpha]_D^{20} = -9.2$ ($c = 2.8$, $CHCl_3$). IR: 2980, 2960, 1685, 1465. ^{1}H-NMR: 0.94 (*t*, $J = 7$, 3 H); 1.01 (*s*, 3 H); 1.13 (*m*, 1 H); 1.17 (*s*, 3 H); 1.69 (*m*, 2 H); 2.12 (*dd*, $J = 11, 15, 1$ H); 2.55 (*dd*, $J = 4, 15, 1$ H); 5.85 (*d*, $J = 9$, 1 H); 6.65 (*d*, $J = 9$, 1 H). ^{13}C-NMR: *Table 3*. MS: 152 (10, $M^{+\cdot}$), 124 (15), 110 (77), 95 (100), 81 (60), 69 (48), 67 (52), 41 (33).

(−)-(5S)-2,4,4,5-Tetramethylcyclohex-2-en-1-one ((−)-**5c**). Obtained in 71% yield from (+)-**4c** following *Procedure i* and *ii*. B.p. 96°/25 Torr. $[\alpha]_D^{20} = -62.4$ ($c = 5.38$, $CHCl_3$). IR: 2980, 1675, 1450, 1360, 1180, 1100, 1000. ^{1}H-NMR: 0.96 (*d*, $J = 7$, 3 H); 0.98 (*s*, 3 H); 1.12 (*s*, 3 H); 1.74 (*s*, 3 H); 2.01 (*m*, 1 H); 2.30 (*m*, 2 H); 6.41 (*s*, 1 H). ^{13}C-NMR: *Table 3*. MS: 152 (42, $M^{+\cdot}$), 137 (10), 110 (75), 95 (69), 83 (100), 67 (82), 55 (39), 41 (38). Mint.

(−)-(5S)-5-Ethyl-2,4,4-trimethylcyclohex-2-en-1-one ((−)-**5d**). Obtained in 68% yield from (+)-**4d** following *Procedure i* and *ii*. B.p. 80°/3 Torr. $[\alpha]_D^{20} = -11.9$ ($c = 2.47$, $CHCl_3$). IR: 2965, 1680, 1465, 1365, 1175, 1015. ^{1}H-NMR: 0.93 (*t*, $J = 7$, 3 H); 0.97 (*s*, 3 H); 1.07 (*m*, 1 H); 1.13 (*s*, 3 H); 1.65 (*m*, 2 H); 1.74 (*d*, $J = 2$, 3 H); 2.12 (*dd*, $J = 16, 18$, 1 H); 2.55 (*dd*, $J = 4, 16$, 1 H); 6.40 (*d*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 166 (39, $M^{+\cdot}$), 137 (22), 124 (39), 109 (96), 95 (80), 83 (94), 67 (100), 55 (39), 41 (34). Camphor, cellar.

(−)-(3S)-3,4,4-Trimethylcyclohexan-1-one ((−)-**6a**). Obtained in 98% yield after hydrogenation of (−)-**5a** following *Procedure iii*. B.p. 75°/3 Torr. 80°/12 Torr. $\alpha_D^{20} = -12.35$. IR: 2940, 1700, 1450, 1280, 1240, 1140, 1080, 1005. ^{1}H-NMR: 0.91 (*d*, $J = 7$, 3 H); 0.99 (*s*, 3 H); 1.03 (*s*, 3 H); 1.59 (*dt*, $J = 4, 15$, 1 H); 1.73 (*m*, 2 H); 2.15 (*m*, 1 H); 2.26 (*m*, 2 H); 2.40 (*m*, 1 H). ^{13}C-NMR: *Table 4*. MS: 140 (56, $M^{+\cdot}$), 125 (47), 83 (20), 70 (63), 55 (83), 41 (100).

Table 4. *^{13}C-NMR Data of Compounds* **6a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(4)[a]	Me(*cis*)–C(4)[a]	R^1	R^2	
(−)-**6a**[b][c]	H	Me	212.5	38.4	40.0	32.6	41.6	46.0	28.6	19.1		16.5	
(+)-**6b**[b][c]	H	Et	212.3	38.3	40.5	33.0	48.9	42.3	28.8	19.6		23.3	12.2
(−)-*trans*-**6c**[c]	Me	Me	213.0	41.4	51.0	33.6	42.8	46.3	28.9	18.5	14.2	16.4	
(+)-*cis*-**6c**[d]	Me	Me	213.6	41.6[e]	45.5	33.2	40.9[e]	42.8	27.9[f]	27.8[f]	14.5	16.1	
(+)-*trans*-**6d**[c]	Me	Et	213.3	41.3	51.2	33.9	50.1	42.6	28.9	19.3	14.3	23.6	12.3
(+)-*cis*-**6d**[d]	Me	Et	214.2	40.8	44.9	33.6	48.6	40.7	28.2[e]	27.4[e]	14.5	21.8	12.6

[a]) Relative to R^2.
[b]) With C(2) bearing R^1 = H.
[c]) 2D Experiments: COSY and C,H correlations.
[d]) Deduced from the hydrogenation mixture before epimerization.
[e])[f]) Interchangeable.

(+)-(3S)-3-Ethyl-4,4-dimethylcyclohexan-1-one ((+)-**6b**). Obtained in 81% yield after hydrogenation of (−)-**5b** following *Procedure iii*. B.p. 90°/12 Torr. $[\alpha]_D^{20} = +21.4$, $[\alpha]_{578}^{20} = +22.4$, $[\alpha]_{546}^{20} = +26.0$, $[\alpha]_{436}^{20} = +50.9$, $[\alpha]_{365}^{20} = +103.9$ ($c = 2.0$, $CHCl_3$). IR: 2960, 1720, 1470, 1390, 1150. ^{1}H-NMR: 0.88 (*t*, $J = 7$, 3 H); 0.99 (*s*, 3 H); 1.00 (*m*, 1 H); 1.03 (*s*, 3 H); 1.40 (*m*, 1 H); 1.60 (*m*, 1 H); 1.68 (*m*, 2 H); 2.03 (*dd*, $J = 11, 14$, 1 H); 2.27 (*m*, 1 H); 2.40 (*m*, 1 H); 2.46 (*m*, 1 H). ^{13}C-NMR: *Table 4*. MS: 154 (25, $M^{+\cdot}$), 139 (19), 125 (78), 83 (91), 70 (64), 55 (100), 41 (53). Sawdust, mouldy, humus, camphor.

(−)-(2R,5S)-2,4,4,5-Tetramethylcyclohexan-1-one ((−)-**6c**). Obtained in 85% yield from (−)-**5c** as a 65:35 *cis*/*trans*-mixture ($\alpha_D^{20} = +10.7$) after hydrogenation following *Procedure iii*. This mixture was epimerized according to *Procedure iv* to give a 12:88 *cis*/*trans*-mixture in 80% overall yield. B.p. 61°/9.5 Torr; 84°/12 Torr. $\alpha_D^{20} = -19.3$, $[\alpha]_D^{20} = -22.1$ ($c = 2.07$, $CHCl_3$). IR: 2950, 1700, 1450, 1370. ^{1}H-NMR: 0.90 (*d*, $J = 7$, 3 H); 0.97 (*s*, 3 H); 0.99 (*d*, $J = 7$, 3 H); 1.03 (*s*, 3 H); 1.32 (*m*, 1 H); 1.67 (*m*, 1 H); 1.73 (*dd*, $J = 7, 15$, 1 H); 2.19 (*m*, 2 H); 2.49 (*sept.*, $J = 7$, 1 H). ^{13}C-NMR: *Table 4*. MS: 154 (22, $M^{+\cdot}$), 139 (10), 112 (18), 83 (45), 69 (100), 55 (38), 41 (44).

(+)-(2R,5S)-5-Ethyl-2,4,4-trimethylcyclohexan-1-one ((+)-**6d**). Obtained in 95% yield after hydrogenation of (−)-**5d** following *Procedure iii* as a 53:47 *cis*/*trans*-mixture ($[\alpha]_D^{20} = +40.3$ ($c = 1.3$, CCl_4)). This mixture was epimerized following *Procedure iv* to give a 21:79 *cis*/*trans*-mixture in 86% overall yield. B.p. 85°/2 Torr. $[\alpha]_D^{20} = +14.5$ ($c = 2.1$, $CHCl_3$). IR: 2965, 1715, 1460, 1390, 1145. ^{1}H-NMR: 0.88 (*t*, $J = 7$, 3 H); 0.98 (*s*, 3 H); 1.00 (*d*, $J = 7$, 3 H); 1.02 (*m*, 1 H); 1.04 (*s*, 3 H); 1.25 (*m*, 1 H); 1.35 (*m*, 1 H); 1.60 (*m*, 1 H); 1.71 (*dd*, $J = 7, 15$, 1 H); 2.02 (*t*, $J = 15$, 1 H); 2.44 (*dd*, $J = 4, 15$, 1 H); 2,52 (*m*, 1 H). ^{13}C-NMR: *Table 4*. MS: 168 (18, $M^{+\cdot}$), 139 (10), 126 (20), 83 (100), 69 (40), 55 (41), 41 (27), Green.

(+)-(1S)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-acetic Acid ((+)-**7**). To a soln. of *t*-BuOK (25.0 g, 0.22 mol) in THF (75 ml) was added dropwise at −78° BuLi (89.2 ml, 2.5M in hexane, 0.22 mol), then (+)-α-pinene (24.2 g, 0.18 mol) in 1 h. The mixture was stirred at r.t. for 48 h, then dissolved with THF (100 ml), cooled to −78° and added dropwise *via* a canula to a mechanically stirred suspension of dry ice in THF (100 ml). The soln. was stirred at −78° for an additional 3 h, with addition of dry ice, then warmed to r.t. and poured into H_2O. The org. phase was

separated, and the aq. phase was extracted with Et_2O (3 × 50 ml). The aq. phase, acidified at 0° with conc. aq. HCl, was extracted with AcOEt (5 × 100 ml). The dried (Na_2SO_4) org. phase was evaporated to afford pure (+)-**7** (78%) as a colorless oil, after bulb-to-bulb distillation. B.p. 100°/0.1 Torr. α_D^{20} = +26.5. IR: 3300, 2920, 1710, 1410, 1300, 950. ^{1}H-NMR: 0.84 (*s*, 3 H); 1.22 (*d*, *J* = 7, 1 H); 1.28 (*s*, 3 H); 2.08 (*m*, 1 H); 2.14 (*dt*, *J* = 2, 6, 1 H); 2.25 (br. *q*, *J* = 14, 2 H); 2.40 (*dt*, *J* = 8, 6, 1 H); 3.04 (*dq*, *J* = 2, 12, 2 H); 5.44 (*m*, 1 H); 12.5 (br. *s*, 1 H, OH). ^{13}C-NMR: 20.9 (Me(*endo*)–C(6)); 26.2 (Me(*exo*)–C(6); 31.4 (C(4)); 31.7 (C(7)); 38.1 (C(6)); 40.5 (C(5)); 42.3 (C(10)); 45.9 (C(1)); 121.3 (C(3)); 140.4 (C(2)); 177.6 (C(11)). MS: 180 (3, $M^{+\cdot}$), 136 (13), 119 (25), 105 (23), 91 (100), 79 (23). Civet, honey, green, acidic.

(+)-(3S)-2,2,3-Trimethyl-6-methylidenecyclohexan-1-one ((+)-**8**). To a mixture of trifluoroacetic-acid-*N*-methylaniline salt (35.5 g, 0.16 mol, m.p. 66°) and $(HCHO)_3$ (43.4 g, 0.48 mol) was added dropwise a soln. of (+)-**3a** (15.0 g, 0.107 mol) in THF (100 ml). The soln. was refluxed for 5 h, then cooled and diluted with Et_2O to form a two-phase system. The Et_2O phase was decanted, washed with sat. aq. $NaHCO_3$ soln. (3 × 100 ml), dried (Na_2SO_4), and evaporated to give (+)-**8** in 80% yield. $[\alpha]_D^{20}$ = +6.7 (*c* = 5.01, $CHCl_3$). IR: 2960, 2940, 1690, 1620, 1520, 1450, 1060. ^{1}H-NMR: 0.90 (*d*, *J* = 7, 3 H); 0.98 (*s*, 3 H); 1.15 (*s*, 3 H); 1.20 (*m*, 1 H); 1.60 (*m*, 2 H); 2.0 (*m*, 1 H); 2.5 (*m*, 1 H); 5.09 (br. *s*, 1 H); 5.64 (br. *s*, 1 H). MS: 152 (6, $M^{+\cdot}$), 124 (62), 109 (90), 95 (42), 82 (100), 69 (53), 67 (51), 55 (43), 41 (20).

(+)-(1R,5S)-5,6,6-Trimethylcyclohex-2-en-1-ol ((+)-**9a**). Obtained in 89% yield from (+)-**2a** following *Procedure vi.* t_R (*DB-wax*, 55–80°): *cis*-**9a**: 4.89 min (94%); *trans*-**9a**: 4.16 min (6%). B.p. 80°/1.2 Torr. α_D^{20} = +3.45. IR: 3340, 2965, 2880, 1450, 1020. ^{1}H-NMR: 0.72 (*s*, 3 H); 0.90 (*d*, *J* = 7, 3 H); 1.01 (*s*, 3 H); 1.47 (br. *s*, OH); 1.58 (*m*, 1 H); 1.72 (*m*, 1 H); 1.95 (*m*, 1 H); 3.89 (br. *s*, 1 H); 5.52 (br. *s*, 1 H); 5.69 (*m*, 1 H). ^{13}C-NMR: *Table 5*. MS: 140 (4, $M^{+\cdot}$), 122 (6), 107 (25), 91 (20), 70 (100), 55 (17).

Table 5. *^{13}C-NMR Data of Compounds (+)-***9a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(6)[a])	Me(*cis*)–C(6)[a])	R^1	R^2	
(+)-**9a**[b])	H	Me	76.4	130.4	128.3	32.0	36.7	37.2	24.6	12.0		14.9	
(+)-**9b**[b])	H	Et	76.3	130.2	128.2	28.4	43.8	37.5	24.7	13.0		21.8	12.3
(+)-**9c**[b])	Me	Me	78.9	135.1	123.2	32.0	37.1	37.4	25.0	12.7	19.7	15.3	
(+)-**9d**[b])	Me	Et	78.7	134.8	123.1	28.2	44.2	37.7	25.0	13.8	19.7	21.9	12.4

[a]) Relative to R^2.

[b]) 2D Experiments: COSY and C,H correlations.

(+)-(1R,5S)-5-Ethyl-6,6-dimethylcyclohex-2-en-1-ol ((+)-**9b**). Obtained in 67% yield from (+)-**2b** following *Procedure vi.* t_R (*DB-1*, 120° (iso)): *cis*-**9b**: 7.00 min (93%); *trans*-**9b**: 5.88 min (7%). B.p. 80°/1.5 Torr. α_D^{20} = +4.14. IR: 3350, 2960, 1450, 1025. ^{1}H-NMR: 0.73 (*s*, 3 H); 0.89 (*t*, *J* = 7, 3 H); 1.03 (*s*, 3 H); 1.05 (*m*, 1 H); 1.28 (*m*, 1 H); 1.41 (br. *s*, OH); 1.65 (*m*, 2 H); 2.17 (*m*, 1 H); 3.88 (br. *s*, 1 H); 5.52 (br. *d*, *J* = 9, 1 H); 5.73 (*m*, 1 H). ^{13}C-NMR: *Table 5*. MS: 154 (4, $M^{+\cdot}$), 139 (4), 136 (3), 107 (12), 91 (12), 84 (20), 70 (100).

(+)-(1R,5S)-2,5,6,6-Tetramethylcyclohex-2-en-1-ol ((+))-**9c**). Obtained in 78% yield from (+)-**2c** following *Procedure vi.* t_R (*DB-wax*, 80–110°): *cis*-**9c**: 10.34 min (96%); *trans*-**9c**: 8.86 min (4%). B.p. 78°/9 Torr. M.p. 74–75°. α_D^{20} = +13.8.IR: 3400, 2950, 2860, 1450, 1380, 1020. ^{1}H-NMR: 0.73 (*s*, 3 H); 0.88 (*d*, *J* = 7, 3 H); 1.00 (*s*, 3 H); 1.38 (br. *s*, OH), 1.54 (*m*, 1 H); 1.68 (*m*, 1 H); 1.73 (*s*, 3 H); 1.88 (*m*, 1 H); 3.75 (br. *s*, 1 H); 5.42 (*m*, 1 H). ^{13}C-NMR: *Table 5*. MS: 154 (12, $M^{+\cdot}$), 139 (22), 136 (12), 121 (54), 105 (29), 84 (100), 79 (27), 55 (28), 41 (24). Saffron, camphor.

(+)-(1R,5S)-5-Ethyl-2,6,6-trimethylcyclohex-2-en-1-ol ((+)-**9d**). Obtained in 98% yield from (+)-**2d** following *Procedure vi.* t_R (*DB-wax*, 110–120°): *cis*-**9d**: 3.56 min (93%); *trans*-**9d**: 3.02 min (7%). B.p. 100°/2 Torr. $[\alpha]_D^{20}$ = +45.0 (*c* = 1.7, $CHCl_3$). IR: 3400, 2990, 1460, 1380, 1110, 1030, 970. ^{1}H-NMR: 0.74 (*s*, 3 H); 0.88 (*t*, *J* = 7, 3 H); 1.02 (*s*, 3 H); 1.05 (*m*, 1 H); 1.24 (*m*, 1 H); 1.32 (*d*, *J* = 8, OH); 1.60 (*m*, 2 H); 1.73 (*s*, 3 H); 2.09 (*m*, 1 H); 3.72 (br. *d*, *J* = 8, 1 H); 5.45 (br. *s*, 1 H). ^{13}C-NMR: *Table 5*. MS: 168 (5, $M^{+\cdot}$), 153 (8), 107 (7), 84 (100), 69 (10), 55 (12), 43 (12), 41 (12).

(−)-(1R,5S)-4,4,5-Trimethylcyclohex-2-en-1-ol ((−)-**10a**). Obtained in 98% yield from (−)-**5a** following *Procedure vi.* t_R (*DB-wax*, 55–80°): *cis*-**10a**: 5.72 min (95%); *trans*-**10a**: 4.67 min (5%). B.p. 80°/1 Torr. $[\alpha]_D^{20}$ = −10.0 (*c* = 0.5, CCl_4). $[\alpha]_D^{20}$ = −9.6 (*c* = 0.3, $CHCl_3$). IR: 3280, 2960, 2880, 1460, 1020. ^{1}H-NMR: 0.85 (*s*, 3 H); 0.90 (*d*, *J* = 7, 3 H); 0.97 (*s*, 3 H); 1.33 (*dt*, *J* = 10, 13, 1 H); 1.54 (*m*, 1 H); 1.75 (br. *s*, OH); 1.82 (*ddt*, *J* = 7, 10, 2, 1 H); 4.26 (*m*, 1 H); 5.44 (*dd*, *J* = 2, 10, 1 H); 5.51 (*dt*, *J* = 10, 2, 1 H). ^{13}C-NMR: *Table 6*. MS: 140 (12, $M^{+\cdot}$), 125 (21), 107 (22), 70 (100), 55 (25).

Table 6. *^{13}C-NMR Data of Compounds* **10a–d**

Compound	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me(*trans*)–C(4)[a])	Me(*cis*)–C(4)[a])	R^1	R^2	
(−)-**10a**[b])	H	Me	68.4	128.2	140.9	35.0	36.8	37.8	28.4	21.9		16.1	
(+)-**10b**	H	Et	68.6	128.3	140.9	35.3	44.6	33.6	28.3	22.4		22.5	12.7
(−)-**10c**[b])	Me	Me	70.9	133.6	136.6	35.3	37.2	38.3	28.9	22.1	18.8	16.0	
(+)-**10d**	Me	Et	71.2	133.5	136.8	35.6	44.9	34.1	28.8	22.4	18.7	22.4	12.8

[a]) Relative to R^2.
[b]) 2D Experiments: COSY and C,H correlations.

(+)-(1R,5S)-5-Ethyl-4,4-dimethylcyclohex-2-en-1-ol ((+)-**10b**). Obtained in 95% yield from (−)-**5b** following *Procedure vi.* t_R (*DB-1*,120° (iso)): *cis*-**10b**: 7.39 min (96%); *trans*-**10b**: 5.78 min (4%). B.p. 120°/5 Torr. $[\alpha]_D^{20} = +45.9$ (*c* = 2.1, $CHCl_3$). IR: 3330, 2960, 1465, 1360, 1030. ^{1}H-NMR: 0.84 (*s*, 3 H); 0.94 (*t*, *J* = 7, 3 H); 0.96 (*m*, 1 H); 0.98 (*s*, 3 H); 1.17 (*m*, 2 H); 1.55 (*m*, 1 H); 2.07 (*m*, 1 H); 2.15 (br. *s*, OH); 4.21 (*t*, *J* = 7, 1 H); 5.41 (*dd*, *J* = 2, 11, 1 H); 5.51 (*dt*, *J* = 11, 2, 1 H). ^{13}C-NMR: *Table 6*. MS: 154 (2, M^+), 139 (16), 107 (18), 84 (100), 69 (75), 55 (21).

(−)-(1R,5S)-2,4,4,5-Tetramethylcyclohex-2-en-1-ol ((−)-**10c**). Obtained in 97% yield from (−)-**5c** following *Procedure vi.* t_R (*DB-wax*, 80–100°): *cis*-**10c**: 11.65 min (93%); *trans*-**10c**: 9.88 min (7%). B.p. 80°/5 Torr. $[\alpha]_D^{20} = -3.5$ (*c* = 0.05, CCl_4). IR: 3340, 2960, 1451, 1010. ^{1}H-NMR: 0.83 (*s*, 3 H); 0.89 (*d*, *J* = 7, 3 H); 0.94 (*s*, 3 H); 1.40 (*m*, 1 H); 1.53 (*m*, 1 H); 1.70 (br. *s*, OH); 1.72 (*d*, *J* = 2, 3 H); 1.85 (*ddd*, *J* = 2, 7, 10, 1 H); 4.13 (*dd*, *J* = 7, 10, 1 H); 5.17 (br. *s*, 1 H). ^{13}C-NMR: *Table 6*. MS: 154 (17, M^+), 139 (22), 121 (25), 95 (25), 84 (100), 69 (55), 55 (26), 43 (36).

(+)-(1R,5S)-5-Ethyl-2,4,4-Trimethylcyclohex-2-en-1-ol ((+)-**10d**). Obtained in 98% yield from (−)-**5d** following *Procedure vi.* t_R (*DB-wax*, 110–120°): *cis*-**10d**: 4.02 min (96%); *trans*-**10d**: 3.09 min (4%). B.p. 100°/1 Torr. $[\alpha]_D^{20} = +9.1$ (*c* = 1.35, CCl_4). IR: 3240, 2965, 1465, 1360, 1330, 1110, 1070, 1015. ^{1}H-NMR: 0.82 (*s*, 3 H); 0.94 (*t*, *J* = 7, 3 H); 0.95 (*s*, 3 H); 0.96 (*m*, 1 H); 1.21 (*m*, 2 H); 1.45 (br. *s*, OH); 1.55 (*m*, 1 H); 1.72 (*s*, 3 H); 2.10 (*dd*, *J* = 7, 15, 1 H); 4.10 (br. *s*, 1 H); 5.13 (*s*, 1 H). ^{13}C-NMR: *Table 6*. MS: 168 (14, M^+), 150 (27), 135 (29), 121 (100), 107 (94), 84 (99), 69 (86), 41 (57).

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