Electrophile-Initiated Cyclobutane Ring Cleavage of (+)-*cis*-3-Methylnopinone

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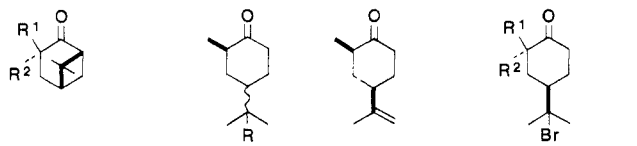
Electrophile-initiated cleavage reactions of the cyclobutane ring in (+)-*cis*-3-methylnopinone (**2**) were studied. (4*R*,6*R*)-(+)-1-Acetoxy-4-(1-acetoxy-1-methylethyl)-6-methyl-1-cyclohexene (**10**) of good optical purity was obtained in high yield on treatment of **2** with BF_3·OEt_2 in the presence of $Zn(OAc)_2$ in acetic anhydride. (2*R*,4*R*)-(−)-2-Methyl-4-isopropenylcyclohexanone (**5**) was derived from **10** by selective hydrolysis, giving (2*R*,4*R*)-(+)-2-methyl-4-(1-acetoxy-1-methylethyl)cyclohexanone (**13**), followed by pyrolysis. Iodotrimethylsilane also reacted efficiently to give the ring cleavage product, *cis*-2-methyl-4-(1-iodo-1-methylethyl)cyclohexanone (**8**).

Since Wallach first observed that the reaction of (+)-nopinone (**1**) with mineral acid selectively cleaved its cyclobutane ring to give C(4)-substituted cyclohexenones and dimerization product,[1,2] several studies have been devoted to this subject.[3] Thermal cleavage of **1** has also been studied.[4]

A similar cleavage reaction of (+)-*cis*-3-methylnopinone (**2**), readily derivable from **1**, was described by Van Der Gen et al., who employed aqueous sulfuric acid or a mixture of sulfuric acid and hydrochloric acid.[5] While alcohol **3** or chloride **4** was the product in this reaction, a serious problem, i.e., almost complete racemization of the product, was encountered.[6] This problem was then overcome by one of us (A.Y.) by employing pyrolytic cleavage of **2**, wherein **2** yielded optically active *cis*-2-methyl-4-isopropenylcyclohexanone (**5**) though the yield was only 38%.[7] To our knowledge, this pyrolysis reaction has since been the sole preparative method for obtaining optically active **6**.[8]

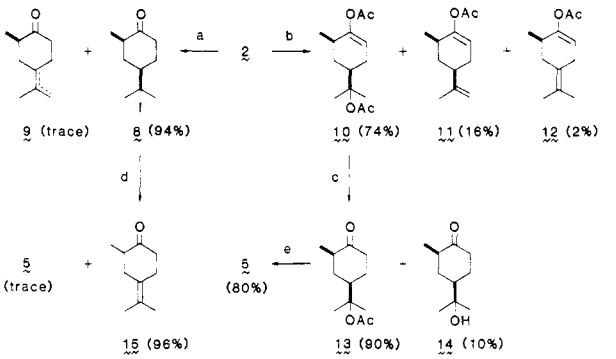


1 R^1=R^2=H **3** R=OH **5** **6** R^1=R^2=D

2 R^1=Me, R^2=H **4** R=Cl **7** R^1=Me, R^2=H

Levine and Gopalakrishnan reported that BBr_3 readily cleaved the cyclobutane ring of α,α-dideuterated **1** to produce bromo ketone **6**, albeit in low yield.[9] This reaction was also applied by Djerassi et al. to the synthesis of optically active 2-methyl homologue **7** (54% yield) from **2**.[10,11]

Scheme I[a]



[a] (a) TMSI, 0 °C to room temperature; (b) BF_3·OEt_2, $Zn(OAc)_2$, Ac_2O, room temperature; (c) K_2CO_3, MeOH, 0 °C; (d) Al_2O_3, Et_2O, room temperature; or DBU, PhH, room temperature; (e) 570 °C.

The above-mentioned reaction prompted us to reinvestigate the ring cleavage reaction of **2** initiated by electrophiles, in the expectation that *cis*-2-methylcyclohexanones with a functionalized isopropyl unit at C(4) would be formed without loss of optical integrity.

Results and Discussion

Bromotrimethylsilane was first examined in this reaction of **2** in comparison with BBr_3. While the reaction was sluggish, it proceeded by selective cyclobutane bond cleavage, affording bromo ketone **7** in low yield, along with recovered **2**. On the other hand, reaction of **2** with iodotrimethylsilane, a more electrophilic reagent than its bromo analogue, caused the ring opening smoothly to provide iodo ketone **8** in excellent yield along with a trace amount of olefins **9** (Scheme I). Compound **8**, which was probably formed from the corresponding trimethylsilyl enol ether on hydrolytic workup, could be obtained with satisfactory quality by rapid filtration through a short silica gel column, though it was unstable on standing at room temperature.[12]

Then, we turned our attention to the utilization of electrophile–nucleophile combination for this cleavage reaction. Selective bond fission of **2** with concomitant enol acetate formation proceeded upon treatment with BF_3·OEt_2 in the presence of $Zn(OAc)_2$ as a cocatalyst in acetic anhydride to provide diacetate **10** and a chromatographically inseparable mixture of isopropenyl and isopropylidene acetates **11** and **12** in a ratio of ca. 1:2 as determined by ^1H NMR spectroscopy. Acetates **10**–**12** were not produced without this cocatalyst, while $Zn(OAc)_2$

(1) For recent reviews of the general chemistry of pinane derivatives, see, for example: Whittaker, D. The Monoterpenes in *Chemistry of Terpenes and Terpenoids*; Newman, A. A., Ed.; Academic Press: 1972. Banthorpe, D. V.; Whittaker, D. *Chem. Rev.* **1966**, *66*, 643.

(2) Wallach, O.; Blumann, A. *Justus Liebigs Ann. Chem.* **1907**, *356*, 231.

(3) Rimini, E. *Gazz. Chim. Ital.* **1916**, *46*, 119. Lewis, K. G.; Williams, G. J. *Aust. J. Chem.* **1968**, *21*, 2467. Bessiere-Chrêtien, Y.; Brahim Maklati, M. *Compt. Rend.* **1969**, *269*, 1315.

(4) Mayer, C. F.; Crandall, J. K. *J. Org. Chem.* **1970**, *35*, 2688. Coxon, J. M.; Garland, R. R.; Hartshorn, M. P. *Aust. J. Chem.* **1972**, *25*, 2407.

(5) Van Der Gen, A.; Van Der Linde, L. M.; Witteveen, J. G.; Boelens, H. *Recl. Trav. Chim. Pays-Bas* **1971**, *90*, 1034.

(6) For a discussion of this racemization, see: Yanami, T.; Miyashita, M.; Yoshikoshi, A. *J. Org. Chem.* **1980**, *45*, 607.

(7) Yoshikoshi, A.; Takagi, Y.; Nishimura, T.; Iwamoto, M.; Kojo, K. (T. Hasegawa, Co.) Jpn. Kokai Tokkyo Koho 78,132,541, 1978; *Chem. Abstr.* **1979**, *90*, P 187171e. Takagi, Y.; Nakahara, Y.; Matsui, M. *Tetrahedron* **1978**, *34*, 517.

(8) (Synthesis of racemic **5**) Odom, H. C.; Pinder, A. R. *J. Chem. Soc., Perkin Trans. I* **1972**, 2193.

(9) Levine, S. G.; Gopalakrishnan, B. *Tetrahedron Lett.* **1979**, 699.

(10) (a) Konopelsky, J. P.; Sundararaman, P.; Barth, G.; Djerassi, C. *J. Am. Chem. Soc.* **1980**, *102*, 2737. (b) Konopelsky, J. P.; Djerassi, C. *J. Org. Chem.* **1980**, *45*, 2297. (c) Lee, S.-F.; Edgar, M.; Pak. C. S.; Barth. G.; Djerassi, C. *J. Am. Chem. Soc.* **1980**, *102*, 4784.

(11) (The ring cleavage of a more complex nopinone structure with BBr_3) Boger, D. L.; Mullican, M. D.; Hellberg, M. R.; Patel, M. *J. Org. Chem.* **1985**, *50*, 1904.

(12) $TiCl_4$ and BCl_3 in CH_2Cl_2 afforded a complex mixture of products.

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itself was ineffective unless BF_3·OEt_2 was also present.[13] Enol acetate **10** was readily hydrolyzed to the corresponding ketone **13** (vide post) and its enol acetate function can be expected to provide regioselectively functionalized derivatives.[14]

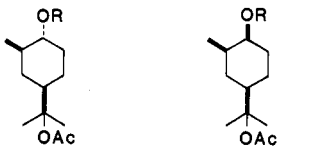
The successful reactions mentioned above reminded us of electrophile-initiated ring-opening reactions of cyclopropyl carbonyl compounds, in which the activated cyclopropane ring is readily cleaved on treatment with iodotrimethylsilane[15a] or BF_3·OEt_2–acetic anhydride.[15b,16] Other combinations of electrophiles and nucleophiles, which have been proven to be superior for the ring fission of cyclopropyl ketones, were thereupon tested for comparison: pyridinium chloride in acetonitrile[15c] and chlorotrimethylsilane–LiCl in acetonitrile[15d] were both ineffective, resulting in the recovery of unreacted **2**, while acetyl methanesulfonate–tetramethylammonium bromide[15e] provided bromo ketone **7** in 50% yield. These results indicated that cyclopropyl ketones are more reactive than the cyclobutyl ketone **2**, presumably because of the larger ring strain of the cyclopropyl group than that of the cyclobutyl group.

Selective hydrolysis of the enol acetate **10** was readily achieved by treatment with K_2CO_3 in methanol to give acetoxy ketone **13**[17] in high yield along with a minor quantity of alcohol **14**.

Some transformations of the side chain (2-iodo-2-propyl in **8** and 2-acetoxy-2-propyl in **13**) into isopropenyl or its isomeric group were conducted as follows: dehydroiodination of **8** over neutral alumina in ether or with DBU in benzene resulted in the regioselective formation of isopropylidene derivative **15** contaminated with a trace quantity of the isopropenyl isomer **5**, while pyrolysis of **13** at 570 °C yielded **5** almost exclusively.[18]

Finally, the optical purity of **13** was established by HPLC analysis of its derivative.[19] Selective hydride reduction of **13** with lithium tri-*tert*-butoxyaluminum hydride in THF afforded a chromatographically separable 4:1 mixture of acetoxy alcohols **16** and **17**.[20] An equatorial configuration of the newly formed hydroxyl group in the major product **16** was evident in that the hydrogen on the carbon-bearing hydroxyl showed a larger half-band width (14.4 Hz) in its ^1H NMR spectrum than that (6.4 Hz) of the minor product **17**.

On treatment with benzoyl chloride in pyridine, **16** and **17** were converted to the corresponding benzoates **18** and **19**, respectively. HPLC analysis employing a DAICEL



16 R=H **17** R=H
18 R=COPh **19** R=COPh

CHIRALPAC OT(+) column with a 19:1 hexane–2-propanol as eluant demonstrated the enantiomeric purity of **19** to be 90%.[21,22] When the ee value (96%) of **1**[23] is taken into account, the observed ee value of **19** establishes that there was almost no loss of optical purity in the cyclobutane ring cleavage reaction of **2** with BF_3·EtO_2–Zn-$(OAc)_2$.

In summary, the regioselective cyclobutane cleavage of 3-methylnopinone (**2**) with iodotrimethylsilane and BF_3·OEt_2–$Zn(OAc)_2$–acetic anhydride produced iodide **8** and diacetate **10** with little loss of optical integrity. The latter product could be converted to the optically active cyclohexanones **5** and **13**, in 53% and 67% overall yields from **2**, respectively.

Experimental Section

^1H NMR spectra were recorded at 90 MHz. HPLC was performed on a Waters Associates combined with a Model 440 absorbance detector. All reactions were carried out under dry N_2 or Ar atmospheres with use of standard procedures for the exclusion of moisture. Column chromatography was performed by using silica gel (Merck, Kieselgel 60, 70–230 mesh), and Kieselgel GF_{254} was employed for preparative thin-layer chromatography (TLC). Solvents for elution are shwon in parentheses.

(+)-*cis*-3-Methylnopinone (2). This ketone **2**, $[\alpha]^{25}_D$ +53.2° (*c* 1.3, $CHCl_3$ (lit.[10] $[\alpha]^{20}_D$ +56.1°, *c* 1.5, $CHCl_3$) was prepared from (+)-nopinone, $[\alpha]^{23}_D$ +36.9° (*c* 4.2, MeOH; 92% optical purity[23]), according to the published procedures.[7] An alternative method (monomethylation of **1**[10b]) afforded a mixture of **2** and its trans isomer.

(2*R*,4*R*)-(+)-2-Methyl-4-(2-bromo-2-methylethyl)cyclohexanone (7). (a) To a stirred solution of **2** (250 mg, 1.64 mmol) in CCl_4 (5 mL) at 0 °C was added bromotrimethylsilane (276 mg, 1.8 mmol). The solution was stirred at room temperature for 48 h and then diluted with Et_2O (30 mL). The solution was washed successively with saturated $NaHCO_3$, water, and brine and then dried. Evaporation of the solvent under reduced pressure left an oil, which was chromatographed on SiO_2 (1:4 Et_2O–hexane) to furnish unreacted **2** (230 mg, 83%) and **7** (26 mg, 7%) as a colorless oil: $[\alpha]^{18}_D$ +6.13° (*c* 0.95, $CHCl_3$); IR (neat) 1715 cm^{-1}; ^1H NMR ($CDCl_3$) 1.05 (d, J = 6, 3 H), 1.2–2.1 (m, 5 H), 1.81 (s, 6 H), 2.2–2.6 (m, 3 H). Anal. Found: C, 51.26; H, 7.10. Calcd for $C_{10}H_{17}OBr$: C, 51.50; H, 7.29.

(b) A mixture of **2** (798 mg, 5.25 mmol), acetyl methanesulfonate[24] (1.47 g, 10.5 mmol), tetramethylammonium bromide (1.63 g, 10.5 mmol), and MeCN (10 mL) was stirred at room temperature for 20 h. The mixture was worked up according to the procedure described in (a) and separation of an oily residue by TLC provided **2** (31 mg, 25%) and **7** (611 mg, 50%).

(2*R*,4*R*)-2-Methyl-4-(2-iodo-2-methylethyl)cyclohexanone (8). To a stirred solution of **2** (152 mg, 1 mmol) in CCl_4 (3 mL) at 0 °C was added iodotrimethylsilane (0.15 mL, 1.1 mmol) and stirring was continued at room temperature for 7 h. A reddish brown solution was diluted with Et_2O (50 mL) and washed with saturated $Na_2S_2O_3$ (25 mL). The organic layer was separated and

(13) NaOAc, KOAc, or $Hg(OAc)_2$ employed in place of $Zn(OAc)_2$ was less effective, and the most of **2** was recovered.

(14) A couple of BF_3·OEt_2 reactions with other nucleophiles such as benzoic anhydride, acetyl chloride, or thiophenol gave fruitless results.

(15) (a) Miller, R. D.; McKean, R. *J. Org. Chem.* **1981**, *46*, 2412. (b) Rigby, J. H.; Senanayake, C. *J. Org. Chem.* **1988**, *53*, 440. (c) Giacomin, E.; Loreto, M. A.; Pellacani, L.; Tardella, P. A. *J. Org. Chem.* **1980**, *45*, 519. (d) Dieter, R. K.; Pounds, S. *J. Org. Chem.* **1982**, *47*, 3174. (e) Demuth, M.; Raghavan, P. K. *Helv. Chim. Acta* **1979**, *62*, 2338.

(16) In the course of our study, it was reported that BF_3·OEt_2–acetic anhydride is an effective reagent for the ring fission of α-cyclopropyl ketones (ref 15b).

(17) This acetoxy ketone **13**, $[\alpha]_D$ +9°, was first prepared by Ohloff and Giersch in five steps from (−)-*cis*-car-4-ene, and its pyrolysis provided **5**, $[\alpha]_D$ −5.5°. The optical rotations of **13** and **5** reported by them are in good agreement with those in this study (see Experimental Section). Ohloff, G.; Giersch, W. *Helv. Chim. Acta* **1968**, *51*, 1328.

(18) The sign of optical rotation of **5** obtained here was opposite to that reported in ref 7. This discrepancy likely arises from a contamination with *trans*-4-isopropenyl-2-methylcyclohexanone in a sample prepared by pyrolysis of **2** in ref 7.

(19) Attempts for determination of enantiomeric compositions of **5** and **13** themselves by HPLC with chiral columns failed.

(20) ^1H NMR using optically active lanthanide shift reagents was unsuccessful in the attempted determination of enantiomeric compositions of the alcohols **16** and **17**.

(21) Chromatographic conditions were set up by the use of racemic **19**, which was prepared from racemic **14** (ref 5) on acetylation with acetyl chloride followed by the sequence of reactions employed for the derivation of its (+) enantiomer.

(22) HPLC analysis of **18** gave no informative results under similar conditions.

(23) The $[\alpha]_D$ value of optically pure **1** has been estimated. Grimshaw, J.; Grimshaw, J. T.; Juneja, H. R. *J. Chem. Soc., Perkin Trans. I* **1972**, 50.

(24) Karger, M. H.; Mazur, Y. *J. Org. Chem.* **1971**, *36*, 528.

dried. Removal of the solvent left a brown oil, which was filtered through a short SiO_2 column (1:9 Et_2O–hexane) to give **8** (268 mg, 94%) as a colorless oil: $[\alpha]^{24}_D$ +5.62° (*c* 0.18, $CHCl_3$); IR (neat) 1715 cm^{-1}; ^1H NMR ($CDCl_3$) 1.60 (d, *J* = 6, 3 H), 1.2–1.9 (m, 6 H), 2.02 (s, 6 H), 2.2–2.5 (m, 3 H).

(4*R*,6*R*)-(+)-1-Acetoxy-4-(2-acetoxy-2-methylethyl)-6-methyl-1-cyclohexene (10). Freshly distilled BF_3·OEt_2 (360 mg, 2.53 mmol) was added dropwise to a stirred suspension of **2** (908 mg, 5.98 mmol), $Zn(OAc)_2$ (1.095 g, 5.97 mmol), and acetic anhydride (10 mL) at 0 °C. The resulting mixture was allowed to warm to 15 °C over a period of 10 h with stirring. The reaction mixture was then diluted with cold water (50 mL), and stirring was continued for an additional 30 min at room temperature. The product was extracted with Et_2O (3 × 50 mL) and combined extracts were washed successively with saturated $NaHCO_3$, water, and brine and dried. Evaporation of the solvent under reduced pressure left an oil, which was chromatographed over SiO_2 (1.4 Et_2O–hexane) to give a mixture of **11** and **12** (73 mg, 18%) as an oil [IR (neat) 1730 cm^{-1}; ^1H NMR ($CDCl_3$) 0.92, 1.0, and 1.02 (s each, 3 H in total, C-Me), 1.68 and 1.73 (s, respectively, in an integrated ratio of approximately 4:1, isopropylidene and isopropenyl methyls), 1.3–2.8 (m, 6 H), 2.13 (s, 3 H), 4.7 (br s, $=CH_2$), 5.30 (br t, *J* = 4.3, 1 H)] and **10** (1.123 g, 74%) as a viscous oil [$[\alpha]^{12}_D$ +4.87° (*c* 3.84, $CHCl_3$); IR (neat) 1760, 1730 cm^{-1}; ^1H NMR ($CDCl_3$) 0.98 (d, *J* = 6.5, 3 H), 1.0–1.5 (m, 3 H), 1.44 (s, 6 H), 1.6–2.2 (m, 3 H), 1.96 (s, 3 H), 2.13 (s, 3 H), 5.32 (m, 1 H). Anal. Found: C, 66.45; H, 8.46. Calcd for $C_{14}H_{22}O_4$: C, 66.12; H, 8.72.].

(2*R*,4*R*)-(+)-2-Methyl-4-(2-acetoxy-2-methylethyl)cyclohexanone (13) and (2*R*,4*R*)-(+)-2-Methyl-4-(2-hydroxy-2-methylethyl)cyclohexanone (14). A mixture of **10** (1.119 g, 4.41 mmol), anhydrous K_2CO_3 (608 mg, 4.41 mmol), and MeOH (25 mL) was stirred at 0 °C for 30 min. The solvent was removed under reduced pressure, and water was added to the resulting oil. The product was extracted with Et_2O (3 × 5 mL), and the extract was dried. The oil obtained by evaporation was then chromatographed on SiO_2 (1:4 Et_2O–hexane) to afford **13** (849 mg, 90%) as a colorless oil: bp 125–6 °C/2 Torr; $[\alpha]^{20}_D$ +9.76° (*c* 0.43, $CHCl_3$); IR (neat) 1730, 1710 cm^{-1}; ^1H NMR ($CDCl_3$) 1.03 (d, *J* = 6, 3 H), 1.2–2.1 (m, 3 H), 1.43 (s, 6 H), 2.00 (s, 3 H), 2.2–2.6 (m, 3 H). Further elution of the column (1:1 Et_2O–hexane) provided **14** (75 mg, 10%) as a viscous oil: $[\alpha]^{20}_D$ +6.98° (*c* 1.56, $CHCl_3$). Its IR and ^1H NMR spectra were identical with those of **14** reported in the literature.[17]

4-Isopropylidene-2-methylcyclohexanone (15). (1) A mixture of **8** (125 mg, 0.45 mmol), neutral alumina (Brockmann I, 2.8 g), and ether (5 mL) was stirred at room temperature for 20 h. Filtration and rinse of the alumina with ether, followed by removal of the solvent from the combined extracts, left an oil, whose filtration through a short silica gel column with ether–pentane (1:3) provided **15**[5] (65 mg, 96%) as a colorless oil: IR (neat) 1710 cm^{-1}; ^1H NMR ($CDCl_3$) 1.03 (d, *J* = 6, 3 H), 1.73 (s, 6 H), 2.0–2.9 (m, 7 H). Contamination with a trace amount of **5** was discerned in the NMR spectrum by isopropylidene signals at δ 4.73.

(2) A mixture of **8** (265 mg, 0.95 mmol), DBU (152 mg, 1.0 mmol), and benzene (25 mL) was stirred at room temperature for 28 h. After removal of the solvent, the residual oil was purified according to the procedure shown in (1) to give **15** (130 mg, 90%).

(2*R*,4*R*)-(−)-2-Methyl-4-isopropenylcyclohexanone (5). A solution of **13** (540 mg, 2.55 mmol) in toluene (12 mL) was passed through a quartz tube (21 × 1.5 cm) packed with quartz beads at 570 °C with the aid of a N_2 stream, and the vapor was condensed in an ice trap. The condensate was washed with water, dried, and concentrated. The resulting oil was passed through a short SiO_2 column (1:9 Et_2O–hexane) to afford **5** (309 mg, 80%) as a colorless oil: $[\alpha]^{20}_D$ −6.84° (*c* 1.26, EtOH); IR ($CHCl_3$) 3060 (w), 1710, 1640, 885 cm^{-1}; ^1H NMR ($CDCl_3$) 1.03 (d, *J* = 6, 3 H), 1.0–2.8 (m, 8 H), 1.75 (s, 3 H), 4.73 (s, 2 H).

(1*R*,2*R*,4*R*)-4-(2-Acetoxy-2-methylethyl)-2-methylcyclohexanol (16) and (1*S*,2*R*,4*R*)-4-(2-Acetoxy-2-methylethyl)-2-methylcyclohexanol (17). To a stirred solution of lithium tri-*tert*-butoxyaluminum hydride (468 mg, 1.84 mmol) in THF (10 mL) at 0 °C was added dropwise a solution of **13** (303 mg, 1.43 mmol) and stirring was continued for an additional 30 min. Wet Et_2O and then a little amount of water was added, and the resulting suspension was filtered through a short Celite column with the aid of Et_2O. Concentration of the filtrate left an oil, which was purified by TLC (5:3 hexane–Et_2O), to give **16** (208 mg, 68%) and **17** (49 mg, 16%). **16**: colorless oil; $[\alpha]^{20}_D$ −8.3° (*c* 2.8, $CHCl_3$); IR ($CHCl_3$) 3600, 3450, 1720 cm^{-1}; ^1H NMR ($CDCl_3$) 1.02 (d, *J* = 6.0, 3 H), 0.9–2.2 (m, 9 H), 1.40 (s, 6 H), 1.98 (s, 3 H), 3.08 (br, $W_{1/2}$ = 14.4, 1 H). **17**: colorless oil; $[\alpha]^{20}_D$ +21.8° (*c* 0.6, $CHCl_3$); IR ($CHCl_3$) 3600, 3450, 1725 cm^{-1}; ^1H NMR ($CDCl_3$) 0.99 (d, *J* = 6.0, 3 H), 1–2.2 (m, 9 H), 1.41 (s, 6 H), 1.98 (s, 3 H), 3.78 (br s, $W_{1/2}$ = 6.4, 1 H).

(1*R*,2*R*,4*R*)-4-(2-Acetoxy-2-methylethyl)-1-(benzoyloxy)-2-methylcyclohexane (18). A mixture of **16** (60 mg, 0.28 mmol), benzoyl chloride (43 μL), and pyridine (1.5 mL) was stirred at 0 °C for 12 h. The reaction mixture was diluted with Et_2O, washed successively with water, aqueous $CuSO_4$, water, and brine, and then dried. Evaporation of the solvent left an oil, which was purified by TLC (5:1 hexane–AcOEt) to give **18** (80 mg, 91%) as an oil: $[\alpha]^{20}_D$ −40.7° (*c* 1.1, $CHCl_3$); IR ($CHCl_3$) 1725, 1720, 1610 (w), 1590 (w), 1275, 1130, 1110; ^1H NMR ($CDCl_3$) 0.96 (d, *J* = 6.1, 3 H), 1–2.3 (m, 8 H), 1.42 (s, 6 H), 1.99 (s, 3 H), 4.60 (m, $W_{1/2}$ = 18), 7.2–7.6 (m, 3 H), 8.05 (m, 2 H). Anal. Found: C, 71.62; H, 8.25. Calcd for $C_{19}H_{26}O_4$: C, 71.67; H, 8.23.

(1*S*,2*R*,4*R*)-4-(2-Acetoxy-2-methylethyl)-1-(benzoyloxy)-2-methylcyclohexane (19). In a similar manner, the reaction of **17** (13 mg, 0.06 mmol) with benzoyl chloride (9 μL) in pyridine (0.5 mL) gave **19** (19 mg, quantitative) as an oil: $[\alpha]^{20}_D$ +37.8° (*c* 0.5, $CHCl_3$); IR ($CHCl_3$) 1725, 1720, 1610 (w), 1590 (w), 1280, 1120 cm^{-1}; ^1H NMR ($CDCl_3$) 0.97 (d, *J* = 6.1, 3 H), 1–2.4 (m, 8 H), 1.45 (s, 6 H), 2.00 (s, 3 H), 5.20 (br s, $W_{1/2}$ = 6.5), 7.2–7.7 (m, 3 H), 8.05 (m, 2 H). Anal. Found: C, 71.67; H, 8.19. Calcd for $C_{19}H_{26}O_4$: C, 71.67; H, 8.23. The optical purity of **19** was determined by HPLC on a DAISEL CHIRALPAC OT(+) column (25 × 0.46 cm). Elution with 5% propanol in hexane (flow rate, 0.6 mL/min) showed two well-separated peaks (95:5) as detected by UV at 254 nm.

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Registry No. **1**, 38651-65-9; **2**, 27040-88-6; **5**, 118710-90-0; **7**, 74352-61-7; **8**, 118598-73-5; **9**, 118710-91-1; **10**, 118598-74-6; **11**, 118710-92-2; **12**, 118598-75-7; **13**, 118710-93-3; **14**, 118710-94-4; (±)-**14**, 34182-10-0; (±)-**15**, 34181-37-8; **16**, 118598-76-8; **17**, 118598-77-9; **18**, 118710-95-5; **19**, 118710-96-6; (±)-**19**, 118598-72-4.