with 5% HCl and water. The solvent was evaporated, and the resulting residue was chromatographed on silica gel (10 g). Elution with hexane–AcOEt (7:1) gave *N*-Boc-**9** (645 mg, 88% yield) as an oil: ^{1}H NMR δ 0.98 (3 H, d, J = 6 Hz), 0.91 (3 h, 6 Hz), 1.47 (9 H, s), 1.10–2.07 (3 H, m), 2.69–2.96 (2 H, m), 3.50–3.84 (1 H, m), 4.60–4.87 (1 H, m), 7.27 (5 H, br s); this material was used for the following reaction without further purification. To a stirred solution of this in CH_2Cl_2 (2 mL) was added $SOCl_2$ (2 mL) with ice cooling. After the stirring had been continued at room temperature for 12 h, the mixture was decomposed with water, made basic with 28% ammonia, and extracted with $CHCl_3$. The solvent was evaporated, and the remaining residue was chromatographed on silica gel (10 g). Elution with hexane afforded an uncharacterized product, which was discarded. Successive elution with hexane–AcOEt (5:1) gave **16** (129 mg, 23% yield).

Anal. Calcd for $C_{14}H_{19}NO_2$: C, 72.07; H, 8.21; N, 6.00. Found: C, 71.84; H, 8.19; N, 5.98.

4*R*,5*S* Isomer of 16. Method A. This compound was obtained from the 2*S*,3*R* isomer of **15** (500 mg, 2.42 mmol) in 85% yield (478 mg) according to the same conditions used to prepare **10** from **9**: mp 113–115 °C; $[\alpha]_D$ −33.43° (*c* 0.61, MeOH). The spectral data were identical with those of **16**. **Method B.** A stirred mixture of the 2*R*,3*R* isomer of **9** (500 mg, 2.4 mmol), Et_3N (730 mg, 7.2 mmol), and CH_2Cl_2 (10 mL) was treated with Boc_2O (500 mg, 2.7 mmol) with ice cooling and worked up as in the preparation of **16**. The product was treated with $SOCl_2$ (2 mL) and worked up as above to give the 4*R*,5*S* isomer of **16** (120 mg, 21.4% yield).

Anal. Calcd for $C_{14}H_{19}NO_2$: C, 72.07; H, 8.21; N, 6.00. Found: C, 71.95; H, 8.03; N, 6.08.

General Procedure for 3-*tert*-Butoxycarbonylation of 10, 16, and Their Antipodes. To a stirred suspension of NaH (94 mg of a 60% suspension in oil, used after removal of oil by washing with petroleum ether) in THF (5 mL) was added a solution of **10** (or **16** or their antipodes) (500 mg, 2.15 mmol) in THF (5 mL). To this solution was added Boc_2O (400 mg, 2.15 mmol) with ice cooling. After stirring had been continued for 10 h at room temperature, the mixture was poured into H_2O and extracted with $CHCl_3$. The extract was washed with H_2O, dried (Na_2SO_4), and evaporated.

(4*S*,5*S*)-3-(*tert*-Butoxycarbonyl)-4-isobutyl-5-benzyloxazolidin-2-one (11). This compound was obtained in 86% yield (615 mg) as an oil: ^{1}H NMR δ 0.68 (3 H, d, J = 6 Hz), 0.88 (3 h, d, J = 6 Hz), 1.03–1.63 (3 H, m), 1.50 (9 H, s), 2.83 (1 H, dd, J = 7, 14 Hz), 3.04 (1 H, dd, J = 5.5, 14 Hz), 3.87–4.04 (1 H, m), 4.23–4.40 (1 H, m), 7.27 (5 H, br s); EI and CI MS did not give either M^+ or $M^+ + 1$.

4*R*,5*R* Isomer of 11. This compound was obtained in 88% yield (629 mg) as an oil, the spectral data of which were identical with those of **11**.

(4*S*,5*S*)-3-(*tert*-Butoxycarbonyl)-4-isobutyl-5-benzyloxazolidin-2-one (17). This compound was obtained in 85% yield (607 mg): mp 119–121 °C; ^{1}H NMR δ 0.97 (3 H, d, J = 6.5 Hz), 1.01 (3 H, d, J = 6.5 Hz), 1.09–1.69 (3 H, m), 1.53 (9 H, s), 2.86 (1 H, dd, J = 5, 14 Hz), 3.09 (1 H, dd, J = 8, 14 Hz), 4.22–4.43 (1 H, m), 4.62–4.84 (1 H, m), 7.30 (5 H, br s); $[\alpha]_D$ +26.0° (*c* 1.10, MeOH).

Anal. Calcd for $C_{19}H_{27}NO_4$: C, 68.44; H, 8.16; N, 4.20. Found: C, 68.42; H, 8.11; N, 4.01.

4*R*,5*S* Isomer of 17. This compound was obtained in 86% yield (615 mg), mp 120–121 °C. The spectral data were identical with those of **17**: $[\alpha]_D$ −26.7° (*c* 1.05, MeOH).

Anal. Calcd for $C_{19}H_{27}NO_4$: C, 68.44; H, 8.16; N, 4.20. Found: C, 68.40; H, 8.01; N, 4.11.

General Procedure for Oxidation of 11, 17, and Their Antipodes. A mixture of **11** (or **17** or their antipodes) (333 mg, 1 mmol), $RuCl_3 \cdot 3H_2O$ (5.75 mg, 0.022 mmol), $NaIO_4$ (3.2 g, 15 mmol), CH_3CN (2 mL), CCl_4 (2 mL), and H_2O (3 mL) was stirred over 48 h at room temperature. The mixture was extracted with $CHCl_3$. The extract was washed with H_2O, dried (Na_2SO_4), and evaporated. The resulting residue was chromatographed on silica gel (10 g). Elution with hexane–AcOEt (1:1) yielded **12** (or **18**).

(4*S*,5*S*)-3-(*tert*-Butoxycarbonyl)-5-(carboxymethyl)-4-isobutyloxazolidin-2-one (12). This compound was obtained in 85% yield (256 mg): mp 70–72 °C (lit.,[9] oil); $[\alpha]_D$ +23.4° (*c* 1.04, $CHCl_3$) (lit.[9] $[\alpha]_D$ +23.32° (*c* 0.92, $CHCl_3$)). The spectral data were identical with those of the authentic specimen.[9]

4*R*,5*R* Isomer of 12. This compound was obtained in 82% yield (247 mg): mp 70–72 °C; $[\alpha]_D$ −23.5° (*c* 0.92, $CHCl_3$). The spectral data were identical with those of **12**.

(4*S*,5*R*)-3-(*tert*-Butoxycarbonyl)-5-(carboxymethyl)-4-isobutyloxazolidin-2-one (18). This compound was obtained in 83% yield (250 mg): mp 67–69 °C (lit.[16] mp 68–70 °C); $[\alpha]_D$ +34.6° (*c* 0.96, MeOH) (lit.[19] $[\alpha]_D$ +34.64° (*c* 0.56, MeOH)). The spectral data were identical with those of the authentic specimen.[19]

4*R*,5*S* Isomer of 18. This compound was obtained in 83% yield (250 mg): mp 66–69 °C; $[\alpha]_D$ −34.0° (*c* 0.67, MeOH). The spectral data were identical with those of **18**.

Synthesis of (3*S*,4*S*)-Dihydro-4-ethyl-3-hydroxy-4-methyl-2(3*H*)-furanone, a Pantolactone Homologue Isolated from *Marshallia tenuifolia*[1]

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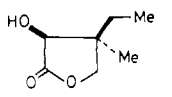
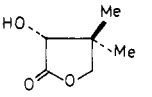
Recently, Herz and Bruno reported the isolation and structural determination of several natural products from the $CHCl_3$ extracts of the above-ground parts of *Marshallia tenuifolia*.[2] These included *p*-hydroxybenzaldehyde, phloroglucinol derivatives, new flavonoids, polyacylated inositols, and optically active γ-lactones. Among these natural products, a hitherto unknown γ-lactone, (3*S*,4*S*)-dihydro-4-ethyl-3-hydroxy-4-methyl-2(3*H*)-furanone (**1**), arouses interest from the biosynthetic point



1



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of view. The absolute configuration of **1** was assigned by comparison of the CD spectrum of **1** with that of (*R*)-dihydro-3-hydroxy-4,4-dimethyl-2(3*H*)-furanone (**2**),[3] a degradation product of pantothenic acid in the liver. The biosynthesis of pantoic acid, (*R*)-2,4-dihydroxy-3,3-dimethylbutanoic acid, from L-valine via α-ketoisovalerate and α-ketopantoate involves an overall inversion at C-2 with the secondary hydroxyl group.

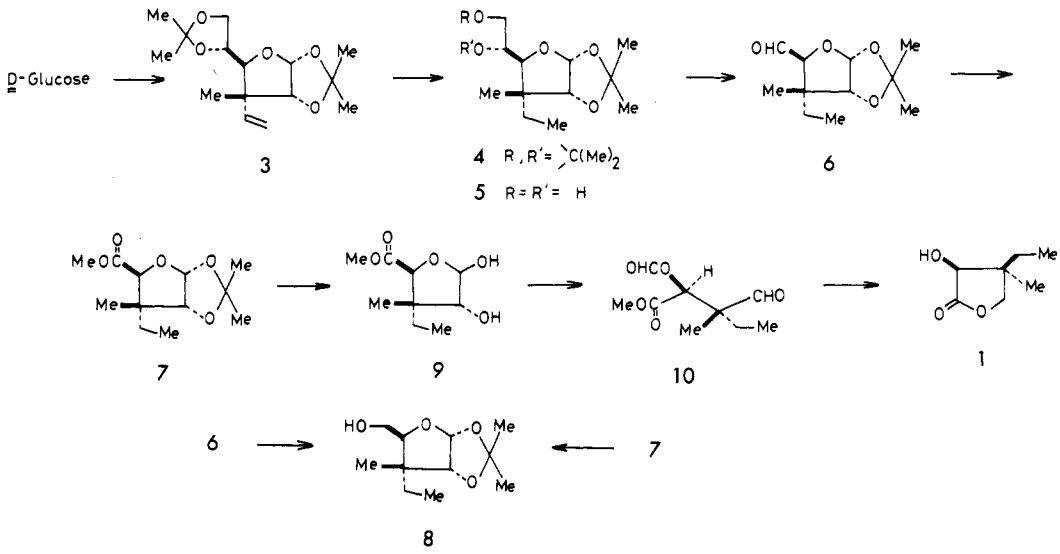
Consequently, if the absolute configuration is correct and if the biosynthesis of **1** follows an analogous course to that of pantoic acid, conversion of L-isoleucine, a likely precursor, into **1** would entail overall retention at C-2 as well as C-3.[2] Therefore, it is important to establish the absolute configuration of **1** for elucidation of the biosynthetic correlation between **1** and **2**. We wish to disclose in this Note the confirmation of the proposed absolute configuration for the pantolactone homologue **1** through its enantiospecific synthesis.

Our synthesis of **1** commenced with the enantiomerically pure highly substituted tetrahydrofuran derivative **3**, which was readily prepared from D-glucose by employing the ortho ester Claisen rearrangement for the introduction of the quaternary carbon.[4] The configuration of the qua-

(1) This work was presented at the 56th National Meeting of the Japan Chemical Society in Tokyo, April 1–4, 1988; Abstract 1IXB30.
(2) Herz, W.; Bruno, M. *Phytochemistry* **1987**, *26*, 1175.
(3) Schippers, P. H.; Dekkers, H. P. J. *Anal. Chem.* **1981**, *53*, 778.

0022-3263/88/1953-3868$01.50/0

Scheme I



ternary carbon (C-4) in **3** was established by chemical modification.[4] Hydrogenation of the vinyl group in **3** in the presence of Raney nickel T-4[5] gave **4** in 99% yield. Selective hydrolysis of the isopropylidene group in the side chain of **4** with 50% aqueous acetic acid under reflux gave **5**. The glycol in **5** was then cleaved by $NaIO_4$ oxidation in aqueous methanol, resulting in **6**, which was further oxidized to the carboxylic acid with potassium permanganate in aqueous methanol in the presence of benzyltriethylammonium chloride.[6] The carboxylic acid thus formed was esterified with diazomethane to provide methyl ester **7** in an overall yield of 68% from **4**. At this stage, we examined whether epimerization of the ester functionality at C-2 occurred during the potassium permanganate oxidation. Therefore, compounds **6** and **7** were independently reduced with sodium borohydride and lithium aluminum hydride, respectively. From these reactions, the same hydroxymethyl derivative **8** was obtained in 81% yield from **6** and 87% yield from **7**. These facts indicate that no epimerization took place under the oxidation conditions employed. Removal of the isopropylidene group in **7** by hydrolysis with 60% aqueous CF_3COOH at room temperature gave **9** as a diastereomeric mixture in 82% yield. Glycol cleavage of **9** with $NaIO_4$ followed by reduction of the intermediary acyclic aldehyde **10** with sodium borohydride provided the desired **1** as a consequence of chemoselective reductions of the *C*-aldehyde and *O*-formyl ester in **10** and successive γ-lactonization. The yield of **1** from **9** was 66%. The specific rotation of the synthetic **1** coincides with that of natural **1** ($[\alpha]^{20}_{546}$ +5.6° for the synthetic **1**, $[\alpha]^{20}_{546}$ +4.7° for natural **1**[2]). Comparison of the ^1H and ^{13}C NMR spectra and TLC behaviors in three different solvent systems revealed that they were identical. Furthermore, the CD curve of synthetic **1** [$[\theta]_{221}$ +11 150 (max)] leads to the conclusion that natural **1** [$[\theta]_{217}$ +15 180 (max)] possesses the 3*S*,4*S* configuration as proposed.

Experimental Section

General Procedures. Reactions were carried out at room temperature unless otherwise described. The reaction mixtures and the combined extracts were concentrated in vacuo by an evaporator at 30–40 °C with a bath. Melting points were determined with a Mitamura Riken micro melting point apparatus and are uncorrected. Specific rotations were measured by a Jasco DIP-4 polarimeter in $CHCl_3$ solutions with a 10-mm cell. Column chromatography was performed with silica gel 60 (Katayama Chemicals K070), and thin-layer chromatography (TLC) was performed on a glass plate coated with Kieselgel 60 GF_{254} (Merck), followed by heating with sulfuric acid. IR spectra were recorded with a Jasco IR-810 spectrometer (neat) and with a Hitachi 225 spectrometer ($CHCl_3$ solution). ^1H NMR spectra (90 MHz) were recorded with a Varian EM-390 spectrometer, and ^1H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded with a JEOL JMN-GX 400 FT NMR spectrometer for $CDCl_3$ solutions with an internal standard of tetramethylsilane.

(2*R*,3*R*,4*R*,5*S*)-4-Ethyl-2,3-(isopropylidenedioxy)-5-[(1*R*)-1,2-(isopropylidenedioxy)ethyl]-4-methyltetrahydrofuran (4). A solution of compound **3**,[4] (2*R*,3*R*,4*R*,5*S*)-2,3-(isopropylidenedioxy)-5-[(1*R*)-1,2-(isopropylidenedioxy)ethyl]-4-methyl-4-vinyltetrahydrofuran (741 mg, 2.60 mmol), in ethanol (15 mL) was hydrogenated in the presence of Raney nickel T-4[5] under 1 atm of hydrogen pressure for 5 h with stirring. The catalyst was removed by filtration. The combined filtrate and washings (15 mL) were concentrated in vacuo to give a TLC-homogeneous **4** as a colorless liquid (738 mg, 99%). An analytical sample was obtained by chromatographic purification on a silica gel column (AcOEt/hexane (1:8)). **4**: TLC R_f 0.61 (AcOEt/hexane (1:4)); $[\alpha]^{24.5}_D$ +30.8° (*c* 1.13); IR ν^{neat}_{max} 2990, 2940, 2880, 1460, 1380, 1370, 1315, 1220, 1165, 1075 cm^{-1}; ^1H NMR (90 MHz) δ 0.91 (s, 3 H, CH_3-4), 0.93 (t, 3 H, *J* = 8 Hz, CH_3CH_2-4), 1.20, 1.22, 1.28, 1.40 (each s, each 3 H, 2 $C(CH_3)_2$), 1.46–1.67 (m, 2 H, CH_3CH_2-4), 3.52–4.07 (m, 4 H, H-5, H-1,2,2′ of the side chain), 4.10 (d, 1 H, *J* = 4 Hz, H-3), 5.60 (d, 1 H, *J* = 4 Hz, H-2). Anal. Calcd for $C_{15}H_{26}O_5$: C, 62.91; H, 9.15. Found: C, 63.10; H, 9.03.

(2*S*,3*S*,4*R*,5*R*)-Methyl 3-Ethyl-4,5-(isopropylidenedioxy)-3-methyltetrahydrofuran-2-carboxylate (7). A solution of **4** (702 mg, 2.45 mmol) in 50% aqueous acetic acid (15 mL) was refluxed for 22 h. The solution was concentrated in vacuo to give crude (2*R*,3*R*,4*R*,5*S*)-4-ethyl-5-[(1*R*)-1,2-dihydroxyethyl]-2,3-(isopropylidenedioxy)-4-methyltetrahydrofuran (**5**) (650 mg, quantitative) as white crystals, which was subjected to the next step directly. In a separate experiment, the crude **5** was purified on a silica gel column (AcOEt/hexane (1:4 to 1:2)). **5**: TLC R_f 0.20 (EtOH/toluene (1:20)); mp 95.5–96.5 °C; $[\alpha]^{25}_D$ +12.3° (*c* 0.87); IR $\nu^{CHCl_3}_{max}$ 3570, 2960, 2930, 2870, 1450, 1380, 1370, 1310, 1245, 1230, 1160, 1070 cm^{-1}; ^1H NMR (90 MHz) δ 0.96 (s, 3 H, CH_3-4), 0.96 (t, 3 H, *J* = 7 Hz, CH_3CH_2-4), 1.30, 1.49 (each s, each 3 H, $C(CH_3)_2$), 1.66 (q, 2 H, *J* = 7 Hz, CH_3CH_2-4), 2.85–3.24 (br, 2 H, 2 OH), 3.56–3.87 (m, 4 H, H-5, H-1,2,2′ of the side chain), 4.19 (d, 1 H, *J* = 4 Hz, H-3), 5.65 (d, 1 H, *J* = 4 Hz, H-2). Anal. Calcd for $C_{12}H_{22}O_5$: C, 58.52; H, 9.00. Found: C, 58.49; H, 8.79.

To a solution of **5** (650 mg, 2.4 mmol) in methanol (18 mL) was added an aqueous solution (2 mL) of sodium periodate (605 mg,

(4) Tadano, K.; Idogaki, Y.; Yamada, H.; Suami, T. *Chem. Lett.* **1985**, 1925; *J. Org. Chem.* **1987**, *52*, 1201.
(5) Nishimura, S. *Bull. Chem. Soc. Jpn.* **1959**, *32*, 61.
(6) $KMnO_4$ oxidation of alkenes in the presence of quaternary ammonium salts. See: Starks, C. M. *J. Am. Chem. Soc.* **1971**, *93*, 195.

2.83 mmol). The solution was stirred for 40 min, and the resulting white solids were removed by filtration. The filtrate was concentrated in vacuo, and the residue was dissolved in water (70 mL). This aqueous solution was extracted with CH_2Cl_2 (100 mL × 3). The extracts were dried over Na_2SO_4 and concentrated in vacuo to give (2*S*,3*R*,4*R*,5*R*)-3-ethyl-4,5-(isopropylidenedioxy)-3-methyltetrahydrofuran-2-carboxaldehyde (**6**) as a colorless syrup, which was subjected to the next step directly. **6**: TLC R_f 0.85 (AcOEt/hexane (1:1)); ^{1}H NMR (90 MHz) δ 0.95 (s, 3 H, CH_3-3), 0.97 (t, 3 H, *J* = 8 Hz, CH_3CH_2-3), 1.33, 1.52 (each s, each 3 H, $C(CH_3)_2$), 1.52–1.97 (m, 2 H, CH_3CH_2-3), 4.02 (d, 1 H, *J* = 2 Hz, H-2), 4.13 (d, 1 H, *J* = 4 Hz, H-4), 5.90 (d, 1 H, *J* = 4 Hz, H-5), 9.70 (d, 1 H, *J* = 2 Hz, CHO).

To a mixture of potassium permanganate (746 mg, 4.72 mmol) and benzyltriethylammonium chloride (55 mg) in water (5 mL) was added a solution of **6** in methanol (2 mL). The mixture was stirred for 2.5 h and methanol (2 mL) was added. The insoluble solids were removed by filtration, and the filtrate was diluted with water (50 mL). This aqueous solution was extracted with AcOEt (100 mL × 5). The combined extracts were dried over Na_2SO_4 and concentrated in vacuo to give crude carboxylic acid (540 mg) as a pale yellow syrup. To a solution of the carboxylic acid in ether (5 mL) was added an etheral solution of diazomethane until the yellow color of the solution was retained. The mixture was stirred at 0 °C for 50 min, and excess diazomethane was removed by warming the mixture to room temperature. The mixture was concentrated in vacuo, and the residue was chromatographed on a silica gel column (30 g, AcOEt/hexane (1:10)). The fraction corresponding to R_f 0.63 (AcOEt/hexane (1:2)) was concentrated in vacuo to give **7** (405 mg, 68% from **4**) as a colorless syrup. **7**: $[\alpha]^{25.5}_D$ +24.1° (*c* 1.19); IR ν^{neat}_{max} 2980, 2940, 2880, 1760, 1730, 1460, 1440, 1380, 1370, 1290, 1250, 1215, 1170, 1145, 1085 cm^{-1}; ^{1}H NMR (90 MHz) δ 0.84 (s, 3 H, CH_3-3), 0.96 (t, 3 H, *J* = 8 Hz, CH_3CH_2-3), 1.30, 1.48 (each s, each 3 H, $C(CH_3)_2$), 1.41–2.03 (m, 2 H, CH_3CH_2-3), 3.73 (s, 3 H, $COOCH_3$), 4.16 (d, 1 H, *J* = 4 Hz, H-4), 4.31 (s, 1 H, H-2), 5.82 (d, 1 H, *J* = 4 Hz, H-5). Anal. Calcd for $C_{12}H_{20}O_5$: C, 59.00; H, 8.25. Found: C, 58.83; H, 8.04.

(2*S*,3*R*,4*R*,5*R*)-3-Ethyl-4,5-(isopropylidenedioxy)-3-methyltetrahydrofuran-2-methanol (8). From 6. Compound **4** (99 mg) was converted into a TLC-homogeneous **6** (72.5 mg) as described in the preparation of **7**. To a solution of **6** (72.5 mg, 0.34 mmol) in methanol (3 mL) was added sodium borohydride (19.5 mg, 0.52 mmol), and the mixture was stirred for 40 min. The mixture was neutralized by addition of Amberlite IR-120 (H^+). The resin was removed by filtration, and the filtrate was concentrated in vacuo. The residue was chromatographed on a silica gel column (4 g, AcOEt/hexane (1:3)) to give **8** (61 mg, 81%) as a colorless syrup. **8**: TLC R_f 0.38 (AcOEt/hexane (1:2)); $[\alpha]^{25.5}_D$ +37.8° (*c* 0.91); IR ν^{neat}_{max} 3450, 2970, 2880, 1455, 1380, 1370, 1310, 1250, 1215, 1170, 1150, 1080, cm^{-1}; ^{1}H NMR (400 MHz) δ 0.81 (s, 3 H, CH_3-3), 0.95 (t, 3 H, *J* = 7.3 Hz, CH_3CH_2-3), 1.31, 1.52 (each s, each 3 H, $C(CH_3)_2$), 1.26, 1.70 (each dq, each 1 H, *J* = 14.2, 7.3 Hz, CH_3CH_2-3), 2.03 (br, 1 H, OH), 3.62 (dd, 1 H, *J* = 11.7, 3.4 Hz, CH_2OH), 3.68 (dd, 1 H, *J* = 11.7, 7.3 Hz, CH_2OH), 3.94 (dd, 1 H, *J* = 7.3, 3.4 Hz, H-2), 4.17 (d, 1 H, *J* = 3.4 Hz, H-4), 5.79 (d, 1 H, *J* = 3.4 Hz, H-5); ^{13}C NMR (100 MHz) δ 8.95 (q), 15.85 (q), 24.85 (t), 26.36 (q), 26.85 (q), 47.36 (s), 62.01 (t), 85.21 (d), 86.93 (d), 104.13 (d), 117.72 (s). Anal. Calcd for $C_{11}H_{20}O_4$: C, 61.09; H, 9.32. Found: C, 61.02; H, 9.14.

From 7. To a solution of **7** (38 mg, 0.16 mmol) in dry THF (2 mL) was added lithium aluminum hydride (12 mg, 0.31 mmol), and the suspension was stirred for 1 h. Water (0.1 mL) was added, and resulting solids were removed by filtration. The filtrate was diluted with water (15 mL) and extracted with CH_2Cl_2 (25 mL × 3). The combined extracts were dried over Na_2SO_4 and concentrated in vacuo. The residue was chromatographed on a silica gel column to give **8** (31 mg, 87%), which was identical with an authentic sample described above in all respects (TLC, $[\alpha]_D$, IR, ^{1}H and ^{13}C NMR).

Diastereomeric Mixture of (2*S*,3*S*,4*R*,5*RS*)-Methyl 3-Ethyl-4,5-dihydroxy-3-methyltetrahydrofuran-2-carboxylates (9). A solution of **7** (135 mg, 0.55 mmol) in 60% aqueous CF_3COOH (6 mL) was stirred for 7 h. After neutralization with 2 M NaOH solution, the solution was extracted with AcOEt (70 mL × 5). The combined extracts were dried over Na_2SO_4 and concentrated in vacuo. The residue was purified by repeated chromatography on a silica gel [(1) 4 g, AcOEt/hexane (1:1); (2) 4 g, AcOEt/hexane (1:2)] to give **9** (92 mg, 82%) as white crystals. **9**: TLC R_f 0.47 (AcOEt/hexane (1:2)); mp 69–71 °C; IR $\nu^{CHCl_3}_{max}$ 3410, 2970, 2880, 1735, 1460, 1435, 1380, 1360, 1280, 1230, 1210, 1140, 1090 cm^{-1}; ^{1}H NMR (90 MHz) δ 0.89 (s, 3 H, CH_3-3), 0.98 (t, 3 H, *J* = 7 Hz, CH_3CH_2-3), 0.89–1.11 (m, 1 H, OH), 1.28–2.02 (m, 3 H, CH_3CH_2-3, OH), 3.76 (s, 3 H, $COOCH_3$), 3.81, 4.00 (each d, total 1 H, each *J* = 4 Hz, H-4), 4.37, 4.47 (each s, total 1 H, H-2), 5.65, 5.79 (each d, total 1 H, *J* = 4 Hz, H-5). Anal. Calcd for $C_9H_{16}O_5$: C, 52.93; H, 7.90. Found: C, 52.77; H, 7.73.

(3*S*,4*S*)-Dihydro-4-ethyl-3-hydroxy-4-methyl-2(3*H*)-furanone (1). To a stirred solution of **9** (82 mg, 0.40 mmol) in methanol (3 mL) was added an aqueous solution (0.5 mL) of sodium periodate (103 mg, 0.48 mmol). The mixture was stirred for 30 min and then diluted with saturated aqueous NaCl solution (40 mL). This was extracted with CH_2Cl_2 (60 mL × 3). The combined extracts were dried over Na_2SO_4 and concentrated in vacuo to give crude (2*S*,3*R*)-methyl 3-formyl-2-(formyloxy)-3-methylpentanoate (**10**) (81 mg) as a colorless syrup. **10**: TLC R_f 0.69 (AcOEt/hexane (1:2)); ^{1}H NMR (90 MHz) δ 0.89 (t, 3 H, *J* = 7 Hz, H-5,5′,5″), 1.15 (s, 3 H, CH_3 at C-3), 1.68 (q, 2 H, *J* = 7 Hz, H-4,4′), 3.80 (s, 3 H, $COOCH_3$), 5.28 (s, 1 H, H-2), 8.08 (s, 1 H, OCHO), 9.53 (s, 1 H, CHO).

To a stirred solution of **10** (81 mg) in methanol (3 mL) was added sodium borohydride (7 mg, 0.19 mmol). The mixture was stirred for 30 min at 0 °C and then at room temperature for 1 h. The solution was neutralized by addition of Amberlite IR-120 (H^+). The resin was removed by filtration, and the filtrate and methanolic washings were combined and concentrated in vacuo. The residue was chromatographed on a silica gel column (3 g, AcOEt/hexane (1:4)). The fraction corresponding to R_f 0.33 (AcOEt/hexane (1:2)) was concentrated in vacuo to give **1** (38.5 mg, 66%) as a colorless syrup. **1**: $[\alpha]^{20}_D$ +3.5° (*c* 0.48), $[\alpha]^{20}_{546}$ +5.6° (*c* 0.48), $[\alpha]^{20}_{365}$ +46.0° (*c* 0.48); CD curve (MeOH) $[\theta]_{221}$ +11 150 (max); IR ν^{neat}_{max} 3430, 2970, 2930, 2880, 1770, 1480, 1460, 1420, 1380, 1340, 1320, 1210, 1190, 1170, 1110, 1000 cm^{-1}; ^{1}H NMR (400 MHz) δ 0.92 (t, 3 H, *J* = 7.3 Hz, CH_3CH_2-4), 1.19 (s, 3 H, CH_3-4), 1.41–1.57 (m centered at δ 1.50, 2 H, CH_3CH_2-4), 3.57 (br s, 1 H, OH), 3.87 (d, 1 H, *J* = 9.3 Hz, H-5), 4.17 (s, 1 H, H-3), 4.20 (d, 1 H, *J* = 9.3 Hz, H-5′); ^{13}C NMR (100 MHz) δ 8.32 (q, CH_3CH_2-4), 20.94 (q, CH_3-4), 24.15 (t, CH_3CH_2-4), 43.56 (s, C-4), 73.75 (t, C-5), 75.84 (d, C-3), 178.15 (s, C-2). Anal. Calcd for $C_7H_{12}O_3$: C, 58.32; H, 8.39. Found: C, 58.04; H, 8.21.

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Stereospecific Synthesis of (*Z*)- and (*E*)-Diethyl (3,3,3-Trifluoro-1-propenyl)phosphonate

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Aliphatic phosphonates have been used as isosteric substitutes for phosphate in numerous studies on biologically relevant systems.[1] Often, the preparation of these target molecules presents a formidable challenge to the

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