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Stereoselective Reduction of α,β-Epoxy Ketones with Sodium Borohydride in the Presence of Calcium Chloride or Lanthanum Chloride. A Practical Preparation of *erythro*-α,β-Epoxy Alcohols

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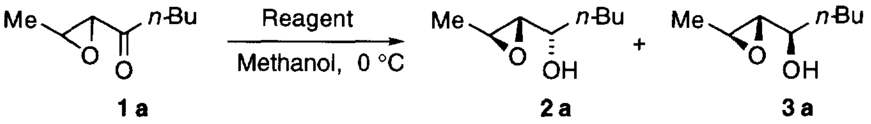
Abstract: *erythro*-Epoxy alcohols were prepared with high stereoselectivity by $NaBH_4$ reduction of the corresponding α,β-epoxy ketones in the presence of calcium chloride or lanthanum chloride regardless of the substituents on the epoxide ring.

The stereoselective synthesis of α,β-epoxy alcohols is a challenging problem for synthetic organic chemists since these moieties are highly versatile intermediates into poly-hydroxy compounds with multiple chiral centers. The stereoselective epoxidation of allylic alcohols has been employed for such purpose. An alternative solution of this problem is the stereoselective reduction of the corresponding α,β-epoxy ketones. Oishi and Nakata have reported highly stereoselective reduction of α,β-epoxy ketones with zinc borohydride.1) Here we wish to report2) an extremely simple and effective alternative procedure for the stereoselective reduction of α,β-epoxy ketones into *erythro*-α,β-epoxy alcohols with $NaBH_4$ in the presence of $CaCl_2$ or $LaCl_3$ in methanol. Recently we have reported that *erythro*-3-hydroxy-2-methyl amides were prepared with high stereoselectivity by $NaBH_4$ reduction of the corresponding β-keto amides in the presence of a catalytic amount of $MnCl_2$ or $CaCl_2$.3) Further extension of this method to the stereoselective reduction of α,β-epoxy ketones provided us with a practical route to *erythro*-α,β-epoxy alcohols.

The α,β-epoxy ketone **1a** was chosen as a substrate and the stereoselectivity of the reduction of **1a** with $NaBH_4$ was examined in the presence of various metal chlorides which were readily soluble in methanol. The results were shown in Table 1 along with the ionic radius of metal cation.4) The stereochemical outcome with $NaBH_4$ or n-Bu_4NBH_4 is also described in the Table. Coexistence of metal salt increased the formation of *erythro* product. It is worth noting that the metal chlorides which have larger ionic radii provided higher *erythro*-selectivity and lanthanum chloride5) provided the highest *erythro* selectivity. The reduction required only 5 min at 0 °C. One exceptional example was a reduction of **1a** with $NaBH_4$ in the presence of $ZnCl_2$ which gave *erythro* product selectively in spite of the retardation of the reaction rate as the case of the reduction of β-keto amides3) (Entry 9). The reduction of **1a** could be conducted in the presence of a catalytic amount of $CaCl_2$ (0.2 mmol) with small loss of stereoselectivity (Entry 5). Meantime, the reduction in the presence of a catalytic amount (0.2 mmol) of lanthanum chloride gave the corresponding epoxy alcohols with higher stereoselectivity compared to the reduction in the presence of 2.0 mmol (Entry 13). Longer reaction time or the excess amount of lanthanoid salts proved to cause partial decomposition of the products into unidentified byproducts.6)

Table 1. Reduction of α,β-Epoxy Ketone **1a**a)



Entry	Reagent (mmol of metal chloride)	Ionic radius of M^{n+} (Å)	Ratio of **2a** : **3a**
1	n-Bu$_4$NBH$_4$b)	–	50 : 50
2	NaBH$_4$b)	–	66 : 34
3	NaBH$_4$-MgCl$_2$ (2)	0.66	70 : 30
4	NaBH$_4$-CaCl$_2$ (2)	0.99	87 : 13
5	NaBH$_4$-CaCl$_2$ (0.2)	–	83 : 17
6	NaBH$_4$-SrCl$_2$ (2)	1.12	89 : 11
7	NaBH$_4$-BaCl$_2$ (2)	1.34	91 : 9
8	NaBH$_4$-MnCl$_2$ (2)	0.80	86 : 14
9	NaBH$_4$-ZnCl$_2$ (2)	0.74	89 : 11
10	NaBH$_4$-YbCl$_3$ (2)	0.858	85 : 15
11	NaBH$_4$-CeCl$_3$ (2)	1.034	88 : 12
12	NaBH$_4$-LaCl$_3$ (2)	1.016	90 : 10
13	NaBH$_4$-LaCl$_3$ (0.2)	–	92 : 8

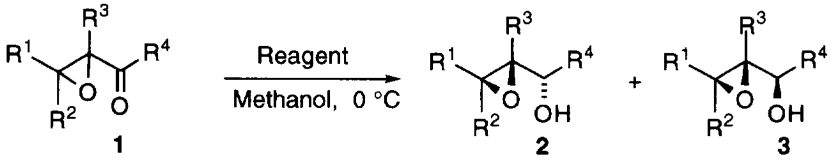
a) Isolated yields were 75–85% b) Epoxy ketone (1.0 mmol) and NaBH$_4$ (or n-Bu$_4$NBH$_4$, 1.0 mmol) were employed.

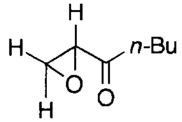
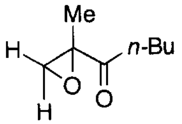
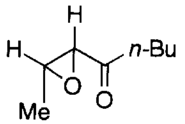
The reduction of **1a** with NaBH$_4$ in the presence of CaCl$_2$ at various temperature was studied and reaction temperature proved to affect the isomeric ratio of **2a** and **3a** slightly. The ratios of **2a** and **3a** were **2a**:**3a** = 87:13 at 25 °C, 88:12 at 0 °C, 89:11 at -24 °C, and 91:9 at -78 °C.

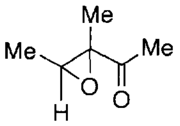
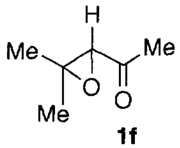
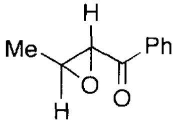
The reduction of various α,β-epoxy ketones with NaBH$_4$ in the presence of CaCl$_2$, MnCl$_2$ or LaCl$_3$ at 0 °C in methanol was examined and the results are shown in Table 2. In order to make a comparison with these data, the results of the reduction with NaBH$_4$ or n-Bu$_4$NBH$_4$ are also described.7) The reduction with NaBH$_4$ or n-Bu$_4$NBH$_4$ in the absence of metal salt proceeded at 0 °C as fast as the reduction with NaBH$_4$ in the presence of metal chlorides. Even at –78 °C, there was little difference in the reaction rate between these two reductions. For instance, treatment of **1c** with NaBH$_4$ at –78 °C for 10 sec gave a mixture of **2c**/**3c** = 71/29 in 80% yield along with recovered **1c** (8%) and the reduction of **1c** with NaBH$_4$ in the presence of CaCl$_2$ at –78

°C for 10 sec provided a mixture of **2c**/**3c** = 80/20 in 72% yield in addition to recovered **1c** (15%). *erythro*-α,β-Epoxy alcohols were produced with high stereoselectivity by NaBH$_4$ reduction in the presence of CaCl$_2$ or LaCl$_3$ irrespective of the substitution pattern of the epoxide. The effect of solvent was investigated. The reduction in ether or benzene proceeded very slowly compared to the reduction in methanol because of insolubility of NaBH$_4$ (or *n*-Bu$_4$NBH$_4$) and metal chlorides. Treatment of **1c** with NaBH$_4$ in ether in the presence of CaCl$_2$ or in the absence of CaCl$_2$ at room temperature for 3 h afforded the same isomeric mixture of **2c**/**3c** = 89/11 in 35% or 40% yield along with recovered **1c** (60% or 55%). Meantime, the reduction of **1c** with *n*-Bu$_4$NBH$_4$ in ether in the absence of CaCl$_2$ did not take place at room temperature. The reduction of **1c** with *n*-Bu$_4$NBH$_4$ in ether in the presence of CaCl$_2$, however, was completed within 3 h at room temperature and provided a mixture of **2c**/**3c** = 66/34 in 85% yield. Treatment of a THF solution of **1c** with Ca(BH$_4$)$_2$, which was prepared from CaCl$_2$ and NaBH$_4$ according to the literature,[8] provided slightly inferior selectivity (**2c**:**3c** = 88:12) compared to our method (Entry 10 in Table 2).

Table 2. Reduction of α,β-Epoxy Ketone [a]



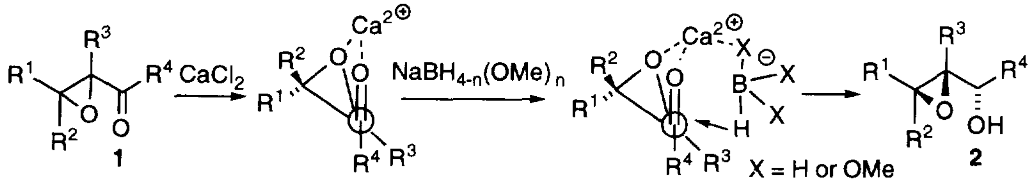
Entry	Substrate	Reagent [b]	Ratio of **2** : **3**
1	 **1b**	*n*-Bu$_4$NBH$_4$	60 : 40
2		NaBH$_4$	65 : 35
3		NaBH$_4$-MnCl$_2$	81 : 19
4		NaBH$_4$-CaCl$_2$	85 : 15
5		NaBH$_4$-LaCl$_3$	90 : 10
6		NaBH$_4$-LaCl$_3$[c]	88 : 12
7	 **1c**	*n*-Bu$_4$NBH$_4$	55 : 45
8		NaBH$_4$	70 : 30
9		NaBH$_4$-MnCl$_2$	92 : 8
10		NaBH$_4$-CaCl$_2$	95 : 5
11		NaBH$_4$-LaCl$_3$[c]	96 : 4
12	 **1d**	*n*-Bu$_4$NBH$_4$	90 : 10
13		NaBH$_4$	90 : 10
14		NaBH$_4$-MnCl$_2$	97 : 3
15		NaBH$_4$-CaCl$_2$	98 : 3
16		NaBH$_4$-LaCl$_3$[c]	>99 : 1

17	 **1e**	n-Bu_4NBH_4	48 : 52
18		$NaBH_4$	42 : 58
19		$NaBH_4$-$MnCl_2$	85 : 15
20		$NaBH_4$-$CaCl_2$	92 : 8
21		$NaBH_4$-$LaCl_3$	92 : 8
22	 **1f**	n-Bu_4NBH_4	83 : 17
23		$NaBH_4$	88 : 12
24		$NaBH_4$-$MnCl_2$	95 : 5
25		$NaBH_4$-$CaCl_2$	97 : 3
26		$NaBH_4$-$LaCl_3$[c]	96 : 4
27	 **1g**	n-Bu_4NBH_4	48 : 52
28		$NaBH_4$	61 : 39
29		$NaBH_4$-$MnCl_2$	87 : 13
30		$NaBH_4$-$CaCl_2$	91 : 9
31		$NaBH_4$-$LaCl_3$[c]	90 : 10

a) Isolated yields were 75–93%. b) Epoxy ketone (1.0 mmol), $NaBH_4$ (or n-Bu_4NBH_4, 1.0 mmol), and metal chloride (2.0 mmol) were employed otherwise noted. c) Catalytic amount of metal chloride (0.2 mmol) was employed.

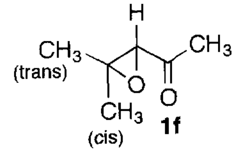
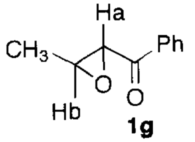
The actual reducing species are not clear at this moment. A vigorous hydrogen evolution occurs upon mixing of $NaBH_4$ with the methanol solution of $CaCl_2$, $MnCl_2$, or the lanthanoid salt. For instance, 80 mL of H_2 was evolved in the methanolysis of $NaBH_4$ (38 mg, 1.0 mmol) with a methanol solution of $CaCl_2$ (220 mg, 2.0 mmol) at 0 °C.[9] This demonstrates an important catalytic effect of Ca^{2+} ion as well as lanthanoid ions in the $MeOH$-BH_4^- reaction. This reaction has been extensively studied and shown to involve the formation of alkoxyborohydrides $NaBH_{4-n}(OMe)_n$.[10] Thus, we assume that the actual reducing species might be a mixture of $NaBH_4$ and $NaBH_{4-n}(OMe)_n$ ($n = 1, 2,$ or 3). The stereoselective formation of the *erythro* product can be rationalized by assuming that hydride attacks the carbonyl carbon from the less hindered side in the similar fashion as shown in a previous report (Scheme 1).[1]

Scheme 1



The ¹H NMR spectral properties of the $CaCl_2$ complex of α,β-epoxy ketone **1f** and **1g** were investigated in CD_3OD at 20 °C in order to substantiate the metal chelation. Upon addition of $CaCl_2$, the signals of methine protons on the epoxide rings were moved downfield. Small downfield shifts were observed for the protons of methyl groups. The chemical shifts and concentration of $CaCl_2$ are shown in Table 3. In the case of **1f**, broadening of signals was not observed. In contrast, the signals of methine protons of **1g** were broadened with increasing concentration of $CaCl_2$. These spectra changes indicate coordination of the calcium ion with epoxy ketone **1f** and **1g** even in such a polar solvent as methanol. The ^{13}C NMR experiments were also studied. The signal of carbonyl carbon moved downfield with increasing the concentration of $CaCl_2$ ($\Delta\delta \sim 1$ ppm).

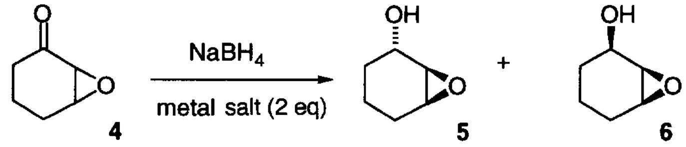
Table 3. ^1H NMR Chemical Shifts (δ) for **1f** and **1g** in the Presence of $CaCl_2$ in CD_3OD at 20 °C

		Equivalent of $CaCl_2$				
		0	0.5	2	4	
1f	Ha	3.60	3.62	3.68	3.75	 **1f**
	CH_3-trans	1.42	1.43	1.44	1.46	
	CH_3-cis	1.22	1.22	1.22	1.24	
	$COCH_3$	2.23	2.24	2.26	2.30	
1g	Ha	4.23	4.25	4.36	4.47	 **1g**
	Hb	3.13	3.14	3.17	3.23	
	CH_3	1.48	1.50	1.51	1.55	

Following experiments also supported the chelation model for the transition state. Reduction of 2,3-epoxycyclohexanone with $NaBH_4$ in the presence of $CaCl_2$ or $BaCl_2$ gave the corresponding epoxy alcohol with poor stereoselectivity in 85% or 83% yield, respectively. The rigid conformation of 2,3-epoxycyclohexanone prevents to coordinate to the metal ions in the chelate manner effectively. On the other hand, the lanthanoid chloride, which has large ionic radius and many coordination site, can form the chelate complex with 2,3-epoxycyclohexanone. The reduction in the presence of lanthanoid chloride such as YCl_3 (2 equivalents) afforded the *trans* epoxy alcohol selectively in the ratio of *trans* : *cis* = 83 : 17[11)] in 60% combined yield (Scheme 2).

The chemical yield and isomeric ratio of the product depended on the reaction conditions in the reduction of **4** under catalysis of lanthanoid chloride. Decrease of the amount of YCl_3 from 2 mmol to 0.2 or 0.5 mmol per 1.0 mmol of **4** proved to give the corresponding epoxy alcohol in better yield (~80%) with small loss of stereoselectivity (0.2 mmol; *trans* : *cis* = 73:27, 0.5 mmol; 77:23). Further treatment of a mixture of **5** and **6** (**5**:**6** = 77:23, 1.0 mmol) with YCl_3 (1.0 mmol) and $NaBH_4$ (1.0 mmol) for 30 min increased the ratio of **5** to **6** (**5**:**6** = 91:9) along with complex byproducts containing 3-chlorocyclohexane-1,2-diol. Based on these facts and Bartel's report, it seems that isomeric ratio of **5** to **6** is moderate (70:30 ~ 75:25) at initial stage in the lanthanoid catalyzed reduction of **4** and increases to 85:15~90:10 upon prolonged exposure of **5** and **6** to YCl_3 since YCl_3 consumes *cis*-epoxy alcohol **6** faster than **5**.

Scheme 2



$NaBH_4$	48 :52
$NaBH_4$ / $CaCl_2$	57 : 43
$NaBH_4$ / $BaCl_2$	54 : 46
$NaBH_4$ / $LaCl_3$	79 : 21
$NaBH_4$ / YCl_3	83 : 17

Experimental

Distillation of the products was performed by the use of Kugelrohr (Büchi), and boiling points are indicated by air-bath temperature without correction. Melting point was obtained on a Yanako MP-50929 melting point apparatus and are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were taken on a Varian GEMINI 300 spectrometer, $CDCl_3$ was used as solvent, and chemical shifts being given in δ with tetramethylsilane as an internal standard. IR spectra were determined on a JASCO IR-810 spectrometer. The analyses were carried out at the Elemental Analysis Center of Kyoto University.

Preparation of α,β-Epoxy Ketone. α,β-Epoxy ketones were prepared by the epoxidation of the corresponding allylic alcohols with *m*CPBA followed by Swern oxidation. α,β-Epoxy ketone **4** was prepared according to the reported procedure.12) Physical data of **1e**,13) **1f**,14) and **4**12) are available in the literature and those of **1a**, **1b**, **1c**, **1d**, and **1g** are shown below.

trans-*2,3-Epoxy-4-octanone (1a)*: Bp 65–66 °C (40 Torr, bath temp) ; IR (neat) 2956, 2930, 2870, 1711, 1460, 1421, 969, 851 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.90 (t, J = 7.3 Hz, 3H), 1.25-1.37 (m, 2H), 1.41 (d, J = 5.1 Hz, 3H), 1.50-1.65 (m, 2H), 2.28 (ddd, J = 17.2, 7.9, 6.9 Hz, 1H), 2.44 (ddd, J = 17.3, 8.2, 6.6 Hz, 1H), 3.13 (qd, J = 5.1, 2.0 Hz, 1H), 3.19 (d, J = 2.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.80, 17.54, 22.23, 25.10, 36.85, 54.32, 60.55, 208.0. Found: C, 67.27; H, 9.83%. Calcd for $C_8H_{14}O_2$: C, 67.57; H, 9.92%.

1,2-Epoxy-3-heptanone (1b): Bp 71–72 °C (50 Torr, bath temp) ; IR (neat) 2956, 2930, 2870, 1714, 1467, 1402, 1381, 868 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.91 (t, J = 7.3 Hz, 3H), 1.25-1.38 (m, 2H), 1.50-1.63 (m, 2H), 2.30 (ddd, J = 17.2, 8.0, 6.8 Hz, 1H), 2.44 (ddd, J = 17.3, 8.1, 6.6 Hz, 1H), 2.87 (dd, J = 5.9, 2.5 Hz, 1H), 3.00 (dd, J = 5.9, 4.7 Hz, 1H), 3.44 (dd, J = 4.7, 2.5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.80, 22.23, 25.10, 36.28, 46.12, 53.38, 207.9. Found: C, 65.56; H, 9.36%. Calcd for $C_7H_{12}O_2$: C, 65.60; H, 9.44%.

1,2-Epoxy-2-methyl-3-heptanone (1c): Bp 74–75 °C (50 Torr, bath temp) ; IR (neat) 2956, 2930, 2870, 1710, 1459, 1380, 1118,1058, 844 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.89 (t, J = 7.3 Hz, 3H), 1.23-1.35 (m, 2H), 1.44-1.60 (m, 2H), 1.50 (s, 3H), 2.23 (ddd, J = 17.4, 8.1, 6.8 Hz, 1H), 2.43 (ddd, J = 17.3, 8.2, 6.4 Hz, 1H), 2.84 (d, J = 5.1 Hz, 1H), 2.96 (dd, J = 5.1, 0.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.84, 16.65, 22.26, 25.48, 34.77, 52.08, 59.56, 209.7. Found: C, 67.48; H, 9.80%. Calcd for $C_8H_{14}O_2$: C, 67.57; H, 9.92%.

cis-*2,3-Epoxy-4-octanone (1d)*: Bp 75–76 °C (40 Torr, bath temp) ; IR (neat) 2956, 2930, 2870, 1720, 1459, 1412, 1384, 1256, 1124, 1046, 953 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.92 (t, *J* = 7.3 Hz, 3H), 1.27 (d, *J* = 5.4 Hz, 3H), 1.28-1.41 (m, 2H), 1.55-1.67 (m, 2H), 2.53 (t, *J* = 7.4 Hz, 2H), 3.33 (qd, *J* = 5.4, 4.9 Hz, 1H), 3.59 (d, *J* = 5.1 Hz, 1H); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 13.01, 13.79, 22.31, 25.23, 40.86, 54.19, 58.53, 206.3. Found: C, 67.78; H, 9.93%. Calcd for $\mathrm{C_8H_{14}O_2}$: C, 67.57; H, 9.92%.

trans-*1-Benzoyl-2-methyloxirane (1g)*: Mp 61.0–62.0 °C ; IR (nujol) 2922, 2852, 1685, 1458, 1417, 1377, 1238, 871, 771, 693, 661 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 1.53 (d, *J* = 5.1 Hz, 3H), 3.23 (qd, *J* = 5.1, 2.0 Hz, 1H), 3.99 (d, *J* = 2.0 Hz, 1H), 7.47-7.54 (m, 2H), 7.59-7.66 (m, 1H), 7.99-8.05 (m, 2H); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 17.62, 55.94, 58.28, 128.3, 134.6, 133.8, 135.5, 194.6. Found: C, 74.05; H, 6.18%. Calcd for $\mathrm{C_{10}H_{10}O_2}$: C, 74.06; H, 6.21%.

General Procedure for the Reduction of α,β-Epoxy Ketones with $NaBH_4$ in the Presence of Metal Chlorides. The reaction of **1g** with $\mathrm{NaBH_4}$ in the presence of $\mathrm{CaCl_2}$ is representative. To a methanol solution of $\mathrm{CaCl_2}$ (220 mg) was added a methanol solution of **1g** (163 mg) at 0 °C. The mixture was stirred for 3 min and $\mathrm{NaBH_4}$ (38 mg) was added. Vigorous gas evolution occurred. After being stirred for another 5 min, the bulk of methanol was removed in vacuo. The resulting mixture was poured into saturated $\mathrm{NH_4Cl}$ and extracted with ethyl acetate (20 ml x 3). The organic layer was dried over $\mathrm{Na_2SO_4}$ and concentrated in vacuo. The isomeric ratio of product was determined by ^{1}H NMR (**2g**/**3g** = 91/9). Purification of the product by silica-gel column chromatography provided a mixture of **2g** and **3g** in 93% combined yield (154 mg). Physical data of **2e**,14) **3e**,14) **2f**,15) **3f**,15) **2g**,16) **3g**,16) **5**,15) and **6**15) are available in the literature and those of **2a**, **3a**, **2b**, **3b**, **2c**, **3c**, **2d**, and **3d** are shown below.

trans-*2,3-Epoxy-4-octanol (mixture of 2a and 3a)*: Bp 69–70 °C (20 Torr, bath temp); IR (neat) 3370, 2956, 2926, 2858, 1466, 1459, 1079, 1017, 869 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.91 (t, *J* = 6.9 Hz, 3H for **2a** and **3a**), 1.23–1.80 (m, 6H for **2a** and **3a**), 1.33 (d, J = 5.3 Hz, 3H for **2a** and **3a**), 1.80–2.00 (bs, 1H for **2a** and **3a**), 2.70 (dd, *J* = 5.3, 2.2 Hz, 1H for **3a**), 2.74 (dd, *J* = 3.1, 2.4 Hz, 1H for **2a**), 2.99 (qd, *J* = 5.2, 2.2 Hz, 1H for **3a**), 3.09 (qd, *J* = 5.2, 2.3 Hz, 1H for **2a**), 3.40–3.50 (m, 1H for **3a**), 3.75–3.82 (m, 1H for **2a**); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 13.99, 17.24, 22.65, 22.72, 27.41, 33.14, 34.03, 50.93, 52.92, 61.90, 62.77, 68.49, 71.30. Found: C, 66.68; H, 11.32%. Calcd for $\mathrm{C_8H_{16}O_2}$: C, 66.63; H, 10.84%.

1,2-Epoxy-3-heptanol (mixture of 2b and 3b): Bp 50–51 °C (15 Torr, bath temp); IR (neat) 3404, 2954, 2928, 2858, 1466, 1459, 1073, 926. 901, 886, 844 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.93 (t, *J* = 7.1 Hz, 3H for **2b** and **3b**), 1.25–2.00 (m, 7H, including OH for **2b** and **3b**), 2.71–2.77 (m, 1H for **2b** and **3b**), 2.80-2.86 (m, 1H for **2b** and **3b**), 2.97–3.01 (m, 1H for **3b**), 3.01–3.05 (m, 1H for **2b**), 3.40–3.48 (m, 1H for **3b**), 3.82–3.89 (m, 1H for **2b**); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 13.95, 22.63, 22.69, 27.40, 33.07, 33.98, 43.38, 45.21, 54.56, 55.47, 68.29, 71.72. Found: C, 64.39; H, 10.90%. Calcd for $\mathrm{C_7H_{14}O_2}$: C, 64.58; H, 11.18%.

erythro-*1,2-Epoxy-2-methyl-3-heptanol (2c)*: Bp 60–61 °C (20 Torr, bath temp); IR (neat) 3400, 2954, 2930, 2860, 1459, 1056 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.92 (t, *J* = 7.1 Hz, 3H), 1.20–1.70 (m, 6H), 1.35 (s, 3H), 2.06 (bs, 1H), 2.61 (d, *J* = 4.8 Hz, 1H), 2.91 (d, *J* = 4.8 Hz, 1H), 3.60–3.70 (m, 1H); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 14.00, 18.15, 22.74, 27.73, 32.57, 50.20, 59.17, 71.46. Found: C, 66.55; H, 11.19%. Calcd for $\mathrm{C_8H_{16}O_2}$: C, 66.63; H, 11.18%.

threo-*1,2-Epoxy-2-methyl-3-heptanol (3c)*: Bp 60–61 °C (20 Torr, bath temp) ; IR (neat) 3418, 2954, 2930, 2860, 1459, 1054 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.92 (t, *J* = 7.1 Hz, 3H), 1.23–1.60 (m, 6H), 1.33 (s, 3H), 2.07 (bs, 1H), 2.68 (d, *J* = 4.6Hz, 1H), 2.78 (d, *J* = 4.7Hz, 1H), 3.25–3.35 (m, 1H); ^{13}C NMR ($\mathrm{CDCl_3}$) δ 13.98, 15.44, 22.66, 27.80, 32.45, 52.71, 59.71, 75.32. Found: C, 66.62; H, 10.88%. Calcd for $\mathrm{C_8H_{16}O_2}$: C, 66.63; H, 11.18%.

(2R,3S*,4S*)-2,3-Epoxy-4-octanol (2d)*: Bp 73–74 °C (20 Torr, bath temp); IR (neat) 3366, 2954, 2928, 2858, 1466, 1458, 1049, 824 cm^{-1}; ^{1}H NMR ($\mathrm{CDCl_3}$) δ 0.93 (t, *J* = 7.0 Hz, 3H), 1.31-1.79 (m, 7H), 1.39 (d, *J* = 5.6 Hz, 3H), 2.84 (dd, *J* = 7.6, 4.1Hz, 1H), 3.11 (qd, *J* = 5.6, 4.1 Hz, 1H), 3.56 (td, *J* = 7.7,

4.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.37, 14.00, 22.69, 27.25, 34.98, 52.78, 59.03, 69.13. Found: C, 66.37; H, 11.12%. Calcd for $C_8H_{16}O_2$: C, 66.63; H, 11.18%.

(2R,3S*,4R*)-2,3-Epoxy-4-octanol (3d)*: Bp 75–76 °C (30 Torr, bath temp); IR (neat) 3404, 2954, 2928, 2858, 1459, 1433, 1091, 1051, 1033, 1014, 834 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.92 (t, J = 7.0 Hz, 3H), 1.30-1.70 (m, 6H), 1.33 (d, J = 5.7 Hz, 3H), 2.08 (bs, 1H), 2.89 (dd, J = 8.1, 4.4Hz, 1H), 3.19 (qd, J = 5.6, 4.4 Hz, 1H), 3.50 (td, J = 7.8, 5.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.87, 13.95, 22.67, 27.05, 33.49, 53.70, 60.80, 69.67. Found: C, 66.64; H, 11.19%. Calcd for $C_8H_{16}O_2$: C, 66.63; H, 11.18%.

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