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A Domino Ring-Opening/Epoxidation of 1,2-Dioxines

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Abstract: When allowed to react with alkaline hydrogen peroxide, monocyclic 1,2-dioxines ring-open to their isomeric γ-hydroxyenone intermediates which are rapidly epoxidized to afford *trans*-4-hydroxy-2,3-epoxyketones in 21−81% yield. In the case of *meso*-1,2-dioxines, Co(II) complex catalyzed asymmetric ring-opening of the 1,2-dioxine may be employed to furnish enantioenriched epoxides

1,2-Dioxines **1** undergo a base catalyzed rearrangement to *cis*-γ-hydroxyenones **2** known as the Kornblum/DeLaMare rearrangement in the presence of bases such as triethylamine, lithium hydroxide, and phosphorus ylides.[1−5] Nucleophiles capture these sensitive γ-hydroxyenones stereospecifically allowing for the synthesis of a range of organic functionalities including tetrahydrofurans, γ-lactones, and cyclopropanes.[2,5−7] We have also developed a procedure for the asymmetric ring-opening of *meso*-1,2-dioxines, and our interest now lies in broadening the scope of nucleophiles that can add to these γ-hydroxyenones.[8]

Weakly basic nucleophiles that can rearrange the 1,2-dioxine and then undergo proton exchange with the γ-hydroxyenone are ideal reagents for reactions with 1,2-dioxines as they allow for one-pot ring-opening/nucleophilic addition reactions. This is highly desirable as the acyclic γ-hydroxyenone motif is unstable as it can dehydrate to furan[9−12] or rearrange to 1,4-diketone[5,13] under acidic or basic conditions, respectively. The hydrogen peroxide anion is a reagent that falls into this category of nucleophile and when allowed to react with α,β-unsaturated ketones gives α,β-epoxyketones by a nucleophilic addition/S_N2 displacement sequence.[14−17] The reaction of 1,2-dioxines with alkaline hydrogen peroxide was therefore hypothesized to give 4-hydroxy-2,3-epoxyketones by a two-step ring-opening/epoxidation one-pot reaction. We have recently synthesized a range of compounds containing this functionality and it was of interest to compare the stereoselectivity that would result from this approach with our earlier procedure.[18]

SCHEME 1

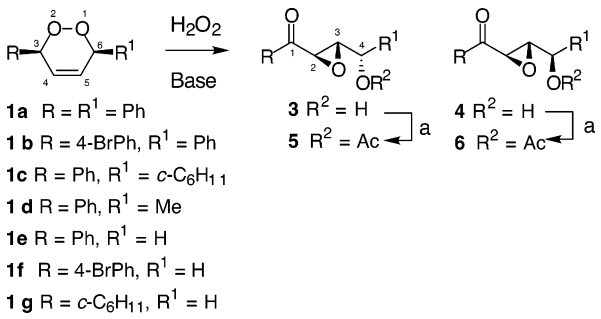

TABLE 1. Reaction of 1,2-Dioxines with Hydrogen Peroxide and Base

entry[a]	dioxine	solvent	base	time (h)	yield[b] (%)	ratio[c] of **3**/**4**
1	**1a**	CH_2Cl_2	LiOH	16	78	60:40
2	**1a**	THF	LiOH	16	81	64:36
3	**1a**	MeOH	LiOH	0.5	79	49:51
4	**1a**	THF	KOH	16	*d*	46:54
5	**1b**	THF	LiOH	3	75	57:43
6	**1c**	THF	LiOH	72	64	65:35
7	**1c**	MeOH	LiOH	16	*d*	60:40
8	**1d**	THF[e]	LiOH	16	70	57:43
9	**1e**	THF	LiOH	48	73	
10	**1e**	MeOH	LiOH	0.5	76	
11	**1f**	MeOH	LiOH	1	72	
12	**1g**	MeOH	LiOH	16	21	

[a] Reactions were conducted at ambient temperature with 1.0 equiv of base and 4.0 equiv of hydrogen peroxide. [b] Refers to combined isolated yield. [c] Ratio determined by ^{1}H NMR on the crude reaction mixture. [d] Yield not determined. [e] 7:1 mixture of THF/MeOH employed as solvent.

1,2-Dioxines **1a**−**f** were prepared by the Rose Bengal sensitized addition of singlet oxygen to the corresponding 1,3-butadienes.[19,20] When 1,2-dioxines **1a**−**f** were allowed to react with alkaline hydrogen peroxide, smooth transformation of the 1,2-dioxine into the trans-substituted epoxides **3** and **4** was observed, Scheme 1 and Table 1. An excess of hydrogen peroxide was employed to suppress dimerization of the γ-hydroxyenone which occurs in the

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presence of hydroxide and alkoxide bases.[2] Initially, the reaction was quenched with the addition of thiosulfate solution; however, the manganese dioxide catalyzed decomposition of the excess hydrogen peroxide gave greater yields of the epoxidation products.

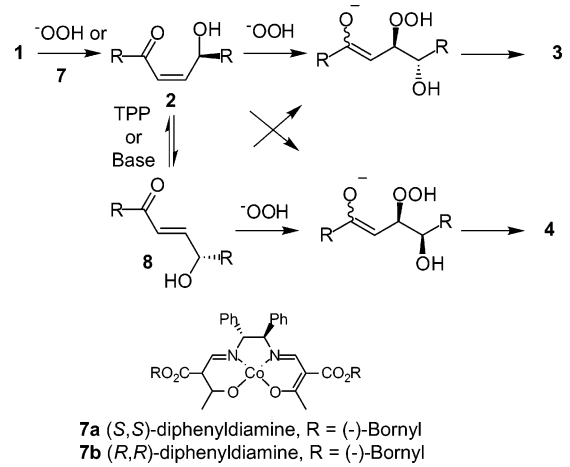
The reaction afforded two products from 3,6-disubstituted-1,2-dioxines **1a**−**d** and only a single product from 3-substituted 1,2-dioxines **1e**,**f**. The reaction was slightly more selective for **3** in THF than methanol; however, a greater rate of reaction was seen in methanol attributed to a faster ring-opening of the parent 1,2-dioxine. The products **3** and **4** were assigned as having *trans*-geometry about the epoxide ring based upon a ∼2 Hz coupling constant between protons on the ring. The X-ray crystal structure obtained for **3a** was used to determine the stereochemistry of the hydroxyl center for **3a** and **4a** and, with the X-ray structure of **3e**,[21] further confirmed the *trans*-assignment for the epoxide. A conserved ^4J coupling of ∼0.5 Hz was seen between protons on C2 and C4 for **3a**−**d** and together with the X-ray structure obtained for **3a** was the basis for the stereochemical assignment of the C4 hydroxyl center. The separation of the isomers **3c** and **4c** was more readily achieved by chromatography after acetylation of the hydroxyl group and consequently were characterized as the acetates.

The reaction regioselectivity was directed by the acidity of the protons at the 3- and 6-position of the 1,2-dioxine. The presence of an aromatic ring at the 3-position significantly increased the acidity of the C3-proton and directed the rearrangement of the 1,2-dioxine. *p*-Bromo substitution on the aromatic ring of **1b** sufficiently increased the acidity of the C3-proton and gave only products from the collapse of the 1,2-dioxine initiated by removal of the C3-proton. It was envisaged that the ring-opening/epoxidation could also be applied to 1,2-dioxines that did not contain a group directing the removal of the 3- or 6-substituted proton in the 1,2-dioxine. For example, exposure of cyclohexyl substituted **1g** to the reaction conditions gave a mixture of products including several aldehydes; however, the major component was still **3g**.

There appeared to be little facial selectivity in the addition of hydrogen peroxide anion to the γ-hydroxyenone and thus both isomers **3** and **4** were formed in the reaction. The use of a more bulky peroxide nucleophile to increase the observed diastereoselectivity did not afford high yields of epoxide. The reaction of **1a** with TBHP/LiOH resulted in significant 1,4-diketone formation via base induced rearrangement of the *cis*-γ-hydroxyenone.[13,19] The low selectivity seen in the reaction can be rationalized when the ability of the γ-hydroxyenone to undergo *cis*/*trans* isomerization is considered. After initial rearrangement of the 1,2-dioxine, the *cis*-γ-hydroxyenone is formed exclusively. Under basic conditions or in the presence of nucleophiles such as triphenylphosphine, equilibrium is established between the *cis*- and *trans*-γ-hydroxyenones, Scheme 2.[2,5] The hydrogen peroxide anion can presumably add to either the *cis* or *trans* enone, both of which can afford **3** or **4**.

To elucidate the stereoselectivity of the reaction when starting from the *trans*-enone, compound **8a** was synthesized. Use of chiral Co(II) catalyst **7a** and **7b** allowed for the asymmetric ring-opening of **1a** to give the optically enriched *cis*-enone which was converted to the *trans*-isomer **8a** by isomerization with triphenylphosphine, Scheme 2.[8]

SCHEME 2



7a (*S*,*S*)-diphenyldiamine, R = (-)-Bornyl
7b (*R*,*R*)-diphenyldiamine, R = (-)-Bornyl

TABLE 2. Epoxidation Reactions of Optically Enriched *trans*-Enone 8a Prepared from 1,2-Dioxine, Co(II) Catalyst, and Triphenylphosphine

			ratio (*R*/*S*)[c]	
entry[a]	catalyst	yield[b] (%)	**3a**	**4a**
1	**7a**	69	44 (86:14)	56 (88:12)
2	**7b**	58	40 (14:86)	60 (15:85)

[a] Reactions were performed on a 1 mmol scale in THF (5 mL) at ambient temperature. [b] Combined isolated yield based upon amount of starting 1,2-dioxine. [c] Enantiomeric ratio measured by converting to the Mosher ester derivative (DCC/Mosher acid/DMAP) and integrating peak height in the crude ^{1}H NMR. *R* and *S* refer to the stereochemistry of the C4 hydroxyl center. Assignment of the absolute stereochemistry is based on the previously observed selectivity; see ref 7.

The reaction of **8a** with hydrogen peroxide gave both **3a** and **4a**; however, the reaction from the *trans*-enone **8a** was more selective for **4a** than when starting from 1,2-dioxine (*cis*-enone), compare Tables 1 and 2. Therefore, the opposing selectivity observed for the epoxidation in the *cis* and *trans* isomers may be responsible for the low diastereoselectivity seen in the reactions of 1,2-dioxines.

The ee's for both the epoxidic products **3a** and **4a** were determined by conversion of the alcohol to the Moshers ester derivative and measuring the de by ^{1}H NMR. Both isomers had ee's within 5% of one another as was expected. The magnitude of the ee's obtained from **1a** utilizing catalysts **7a** and **7b** are in agreement with those found for other reactions of 1,2-dioxines catalyzed by **7a** and **7b**; however, this represents the first reported use of catalyst **7** for the asymmetric synthesis of a *trans*-γ-hydroxyenone.[5,8]

The ring-opening/epoxidation reaction described is an efficient route to *trans*-epoxides such as **3** and **4**. It is a useful adjunct to our previously described methodology for the synthesis of 4-hydroxy-2,3-epoxy ketones as the products have opposite stereochemistry about the epoxide ring.

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Experimental Section

General Procedure for the Epoxidation of 1,2-Dioxines 1a−c. To a stirred solution of 1,2-dioxine (1 mmol) in THF (5 mL) was added 30% aqueous hydrogen peroxide (453 mg, 4 mmol) followed by lithium hydroxide (23 mg, 1 mmol). The resulting suspension was stirred vigorously until all starting material had been consumed (TLC, 16−48 h). Sodium thiosulfate solution (10%, 20 mL) was then added, and the reaction was stirred for 15 min before being diluted with CH_2Cl_2 (40 mL). The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (30 mL). The combined organic extracts were washed with brine (10 mL), dried, and concentrated in vacuo affording the *trans*-epoxides which were separable by flash chromatography and/or recrystallization.

(±)-{(2*R*,3*S*)-3-[(*S*)-1-Hydroxy-1-phenylmethyl]oxiran-2-yl}(phenyl)methanone 3a: colorless solid; mp 106−107 °C (CH_2Cl_2/hexane); R_f 0.50 (60:40 hexane/ethyl acetate); IR (Nujol) 3420, 1666, 1233, 1048, 696 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 2.10−2.70 (br s, 1H), 3.35 (dd, J = 2.7, 2.1 Hz, 1H), 4.47 (dd, J = 2.1, 0.6 Hz, 1H), 5.12 (d, J = 2.7, 0.6 Hz, 1H), 7.34−7.56 (m, 8H), 7.81−7.84 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 53.5, 61.9, 70.1, 125.9, 128.2, 128.5, 128.7, 128.8, 133.8, 135.2, 138.6, 193.8; EIMS *m*/*z* 255 (MH$^+$, 10), 237 (100), 209 (20), 105 (55). Anal. Calcd for $C_{16}H_{14}O_3$: C, 75.57; H, 5.54. Found: C, 74.94; H, 5.31.

(±)-{(2*R*,3*S*)-3-[(*R*)-1-Hydroxy-1-phenylmethyl]oxiran-2-yl}(phenyl)methanone 4a: colorless solid; mp 78−80 °C (CH_2Cl_2/hexane); R_f 0.38 (60:40 hexane/ethyl acetate); IR (Nujol) 3486, 1677, 1230, 1061, 685 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 2.31 (br s, 1H), 3.49 (dd, J = 3.9, 2.4 Hz, 1H), 4.34 (d, J = 2.4 Hz, 1H), 4.81 (d, J = 3.9 Hz, 1H), 7.35−7.62 (m, 8H), 7.87−7.90 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 55.0, 62.1, 72.7, 126.5, 128.3, 128.6, 128.7, 128.9, 133.9, 135.2, 139.5, 193.6; EIMS *m*/*z* 254 (M$^+$, 3), 236 (30), 208 (30), 147 (80), 105 (100). Anal. Calcd for $C_{16}H_{14}O_3$: C, 75.57; H, 5.54. Found: C, 75.53; H, 5.60.

(±)-(4-Bromophenyl){(2*R*,3*S*)-3-[(*S*)-1-hydroxy-1-phenylmethyl]oxiran-2-yl}methanone 3b: colorless solid; mp 138−140 °C (CH_2Cl_2/hexane); R_f 0.26 (70:30 hexane/ethyl acetate); IR (Nujol) 3426, 2923, 1666, 1583, 1455, 1250, 1070, 1045, 1007, 765, 698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.40−1.80 (br s, 1H), 3.45 (dd, J = 2.7, 2.1 Hz, 1H), 4.40 (dd, J = 2.1, 0.6 Hz, 1H), 5.13 (d, J = 2.7, 0.6 Hz, 1H), 7.36−7.47 (m, 5H), 7.52−7.58 (m, 2H), 7.66−7.68 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 53.5, 61.9, 70.0, 125.9, 128.6, 128.9, 129.2, 129.7, 132.1, 133.8, 138.4, 192.9; EIMS *m*/*z* 334 (M$^+$, ^{81}Br, 10), 332 (M$^+$, ^{79}Br, 10), 227 (^{81}Br, 50), 225 (^{79}Br, 45), 107 (100). Anal. Calcd for $C_{16}H_{13}O_3Br_1$: C, 57.68; H, 3.93. Found: C, 57.76; H, 3.81.

(±)-(4-Bromophenyl){(2*R*,3*S*)-3-[(*R*)-1-hydroxy-1-phenylmethyl]oxiran-2-yl}methanone 4b: colorless solid; mp 121−122 °C ($CDCl_3$/hexane); R_f 0.20 (70:30 hexane/ethyl acetate); IR (Nujol) 3446, 1697, 1586, 1229, 1071, 1008, 698; ^{1}H NMR ($CDCl_3$, 200) δ 2.33 (br s, 1H), 3.48 (dd, J = 4.2, 2.2 Hz, 1H), 4.27 (d, J = 2.2 Hz, 1H), 4.81 (d, J = 4.2 Hz, 1H), 7.36−7.49 (m, 5H), 7.56−7.61 (m, 2H), 7.72−7.77 (m, 2H); ^{13}C NMR ($CDCl_3$, 50) δ 55.0, 62.0, 72.8, 126.5, 128.3, 129.0, 129.3, 129.7, 132.1, 133.8, 139.4, 192.8; EIMS *m*/*z* 334 (M$^+$, ^{81}Br, 10), 332 (M$^+$, ^{79}Br, 10), 317 (10), 316 (10), 315 (10), 314 (10), 185 (90), 183 (90), 105 (100); HRMS calcd for (ESI, M + Na$^+$) $C_{16}H_{15}O_3Br_1Na_1$ 354.9945, found 354.9946.

(±)-{(2*R*,3*S*)-3-[(*S*)-1-Cyclohexyl-1-hydroxymethyl]oxiran-2-yl}(phenyl)methanone 3c: colorless solid; mp 128−130 °C (CH_2Cl_2/hexane); R_f 0.39 (70:30 hexane/ethyl acetate); IR (Nujol) 3471, 1670, 1596, 1242, 1043, 703 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.15−1.28 (m, 6H), 1.60−1.87 (m, 6H), 3.30 (dd, J = 2.7, 2.1 Hz, 1H), 3.76 (br dd, J = 6.0, 2.7 Hz, 1H), 4.41 (dd, J = 2.1, 0.3 Hz, 1H), 7.48−7.54 (m, 2H), 7.61−7.66 (m, 1H), 8.04−8.08 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 25.8, 25.9, 26.2, 28.2, 28.7, 41.7, 53.3, 60.9, 72.3, 128.3, 128.8, 133.9, 135.4, 194.2; EIMS *m*/*z* 261 (MH$^+$, 20), 243 (40), 147 (70), 105 (100). Anal. Calcd for $C_{16}H_{20}O_3$: C, 73.82; H, 7.74. Found: C, 73.39; H, 7.59.

(±)-{(2*R*,3*S*)-3-[(*R*)-1-Cyclohexyl-1-hydroxymethyl]oxiran-2-yl}(phenyl)methanone 4c: colorless solid isolated as a mixture with **3c**; R_f 0.35 (70:30 hexane/ethyl acetate); IR (Nujol) 3478, 2925, 2852, 1669, 1597, 1449, 1238 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.06−1.29 (m, 5H), 1.55−1.77 (m, 6H), 1.94 (d, J = 12.3 Hz, 1H), 3.32 (dd, J = 3.0, 2.1 Hz, 1H), 3.56 (dd, J = 5.7, 3.0, 1H), 4.32 (d, J = 2.1 Hz, 1H), 7.48−7.54 (m, 2H), 7.60−7.63 (m, 1H), 8.01−8.05 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 25.8, 25.9, 26.2, 28.3, 28.8, 42.6, 54.4, 60.6, 73.4, 128.3, 128.8, 133.9, 135.4, 194.1.

General Procedure for the Epoxidation of 1,2-Dioxines 1d−f. To a stirred solution of 1,2-dioxine (1 mmol) in THF (5 mL) was added 30% aqueous hydrogen peroxide (453 mg, 4 mmol) followed by lithium hydroxide (23 mg, 1 mmol). The resulting suspension was stirred vigorously until complete (TLC, 16−48 h). A small portion (1−2 mg) of manganese dioxide was then added to the mixture and allowed to stir until evolution of gas had ceased. The solution was then diluted with water (15 mL) and extracted with CH_2Cl_2 (2 × 20 mL). The combined organic extracts were dried and evaporated affording the *trans*-epoxides, which were separable by flash chromatography and/or recrystallization.

(±)-{(2*R*,3*S*)-3-[(1*R*)-1-Hydroxyethyl]oxiran-2-yl}(phenyl)methanone 3d: colorless oil; R_f 0.24 (60:40 hexane/ethyl acetate); IR (neat) 3460, 2977, 1689, 1598, 1450, 1232, 696 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.36 (d, J = 6.3 Hz, 3H), 2.34 (br s, 1H), 3.24 (dd, J = 2.5, 2.2 Hz, 1H), 4.19 (ddq, J = 6.3, 2.5, 0.5 Hz, 1H), 4.41 (dd, J = 2.2, 0.5 Hz, 1H), 7.44−7.66 (m, 3H), 8.02−8.11 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 18.6, 53.2, 62.5, 64.3, 128.2, 128.7, 133.9, 135.4, 194.1; EIMS *m*/*z* 193 (MH$^+$, 95), 147 (50), 105 (100); HRMS calcd for (MH$^+$) $C_{11}H_{13}O_3$ 193.0864, found 193.0866.

(±)-{(2*R*,3*S*)-3-[(1*S*)-1-Hydroxyethyl]oxiran-2-yl}(phenyl)methanone 4d: colorless solid; mp 106−108 °C; R_f 0.21 (60:40 hexane/ethyl acetate); IR (neat) 3378, 2922, 1694, 1598, 1453, 1338, 1231, 901, 700 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.41 (d, J = 6.4 Hz, 3H), 1.71 (br s, 1H), 3.23 (dd, J = 3.4, 2.0 Hz, 1H), 4.00 (dq, J = 6.4, 3.4 Hz, 1H), 4.34 (d, J = 2.0 Hz, 1H), 7.47−7.64 (m, 3H), 8.00−8.05 (m, 2H); ^{13}C NMR ($CDCl_3$, 75) δ 20.3, 54.8, 62.7, 65.9, 128.3, 128.8, 133.9, 135.4, 193.9; EIMS *m*/*z* 193 (MH$^+$, 20), 175 (10), 147 (40), 105 (100). Anal. Calcd for $C_{11}H_{12}O_3$: C, 68.72; H, 6.29. Found: C, 68.83; H, 6.34.

(±)-[(2*R*,3*S*)-3-(Hydroxymethyl)oxiran-2-yl](phenyl)methanone 3e: colorless oil which crystallized at −15 °C; mp 60−62 °C; R_f 0.27 (1:1 hexane/ethyl acetate); IR (neat) 3445, 1686, 1597, 1450, 1233, 1063, 697 cm^{-1}; ^{1}H NMR ($CDCl_3$, 200) δ 2.64 (br s, 1H), 3.37 (ddd, J = 3.0, 2.2, 2.0 Hz, 1H), 3.90 (dd, J = 13.2, 3.0 Hz, 1H), 4.09 (dd, J = 13.2, 2.0 Hz, 1H), 4.42 (d, J = 2.2 Hz, 1H), 7.45−7.67 (m, 3H), 8.00−8.05 (m, 2H); ^{13}C NMR ($CDCl_3$, 50) δ 53.8, 59.3, 60.0, 128.3, 128.7, 133.9, 135.2, 194.3; EIMS *m*/*z* 178 (M$^+$, 5), 160 (25), 147 (25), 105 (100). Anal. Calcd for $C_{10}H_{10}O_3$: C, 67.41; H, 5.66. Found: C, 67.29; H, 5.66.

(±)-(4-Bromophenyl)[(2*R*,3*S*)-3-(hydroxymethyl)oxiran-2-yl]methanone 3f: colorless solid; mp 78−80 °C; R_f 0.30 (1:1 hexane/ethyl acetate); IR (neat) 3500, 3291, 1682, 1586, 1232, 1071 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.67 (br s, 1H), 3.38 (ddd, J = 2.7, 2.4, 2.1 Hz, 1H), 3.91 (dd, J = 17.2, 2.7 Hz, 1H), 4.10 (dd, J = 17.2, 2.4 Hz, 1H), 4.33 (d, J = 2.1 Hz, 1H), 7.64−7.67 (m, 2H), 7.89−7.92 (m, 2H); ^{13}C NMR ($CDCl_3$, 50) δ 53.7, 59.1, 59.8, 129.4, 129.5, 132.2, 133.9, 193.3; EIMS *m*/*z* 258 (M$^+$, ^{81}Br, 5), 256 (M$^+$, ^{79}Br, 6), 224 (30, ^{79}Br), 222 (30, ^{81}Br), 185 (100). Anal. Calcd for $C_{10}H_9O_3Br_1$: C, 46.72; H, 3.53. Found: C, 46.41; H, 3.36.

(±)-[(2*R*,3*S*)-3-(Hydroxymethyl)oxiran-2-yl](cyclohexyl)methanone 3g: colorless oil; R_f 0.50 (1:1 hexane/ethyl acetate); IR (neat) 3443, 2930, 2855, 1704, 1450, 1064 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300) δ 1.18−1.47 (m, 5H), 1.68−1.92 (m, 6H), 2.51 (dddd, J = 11.1, 11.1, 3.3, 3.3 Hz, 1H), 3.22 (ddd, J = 3.3, 2.4, 2.4 Hz, 1H), 3.63 (d, J = 2.4 Hz, 1H), 3.76 (dd, J = 12.9, 3.3 Hz, 1H), 4.01 (dd, J = 12.9, 2.4, 1H); ^{13}C NMR ($CDCl_3$, 50) δ 25.2, 25.6, 25.6, 27.5, 28.3, 46.6, 54.9, 58.0, 60.4, 208.9; EIMS *m*/*z* 185 (MH$^+$, 90), 111 (50), 83 (100); HRMS calcd for $C_{10}H_{16}O_3Na$ (M + Na$^+$) 207.0997, found 207.0993.

Procedure for the Synthesis of Optically Enriched Epoxides 3a and 4a. To a stirred degassed solution of THF (5 mL) cooled to −10 to −15 °C was added Co(II) catalyst **7a** (54 mg, 0.075 mmol). After the solution was stirred for 30 min, 3,6-diphenyl-3,6-dihydro-1,2-dioxine **1a** (238 mg, 1 mmol) was added and the solution allowed to stir at −10 °C for 3 h or until all

1,2-dioxine had been consumed (TLC). Triphenylphosphine (136 mg, 0.50 mmol) was then added and the reaction left to stir for a further 30 min. The reaction was concentrated in vacuo and the *trans*-enone intermediate isolated immediately by column chromatography (Florisil, 60:40 hexane/ethyl acetate) (R_f 0.50). The *trans*-enone was epoxidized immediately using the above procedure as for **1d**−**f**.

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Supporting Information Available: Characterization data for **5c** and **6c**. ORTEP representation and X-ray data for epoxide **3a**. ^{13}C NMR spectra for **3a**,**c**,**d** and **4b**. This material is available free of charge via the Internet at http://pubs.acs.org.

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