10-Bromo-3,7-dimethyl-2,6-decadiene. The procedure was that described above; bp 130 °C at 0.5 Torr. ^{1}H NMR ($CDCl_3$): δ 5.15 (m, 2 H, C=C*H*), 3.36 (t, 2 H, BrCH_2), 2.05 (m, 8 H, CH_2CH_2), 1.59 (m, 9 H, C=CCH_3). ^{13}C NMR: δ 135.34, 132.74, 125.72, 118.41, 39.55, 37.76, 33.36, 30.80, 26.47, 15.73, 15.54, 13.33.

5,9-Dimethyl-1-phenylundeca-5,9-dien-1-ol. This phenyl derivative was prepared in the manner described above. IR (neat): 3400 cm^{-1} (b, -OH). ^{1}H NMR ($CDCl_3$): δ 7.25 (m, 5 H, Ph), 5.15 (m, 2 H, C=C*H*), 4.66 (dd, 1 H, Ph(OH)C*H*), 2.0 (m, 10 H, CH_2), 1.59 (m, 10 H, C=CHCH_3 and OH). ^{13}C NMR ($CDCl_3$): δ 144.83, 135.59, 134.52, 128.30, 127.34, 125.80, 124.54, 118.22, 74.48, 39.65, 39.33, 38.46, 26.53, 23.94, 15.27, 15.01, 13.30.

11-Chloro-3,7-dimethyl-11-phenyl-2,6-undecadiene (2). The procedure used was the same as that described above for **1**. GC analysis showed the product to contain 70% of the desired chloride and 30% of cyclization products. ^{1}H NMR ($CDCl_3$): δ 7.34 (m, 5 H, Ph), 5.15 (m, 2 H, C=CH), 4.83 (dd, 1 H, PhClCH), 1.98 (m, 10 H, CH_2), 1.58 (m, 9 H, C=CHCH_3). ^{13}C NMR ($CDCl_3$): δ 141.96, 135.51, 134.05, 128.26, 128.02, 126.63, 124.99, 118.34, 63.99, 39.62, 39.31, 38.80, 26.50, 25.10, 15.88, 15.68, 13.34.

Solvolysis. The rate constants were measured in 80% (v/v) aqueous ethanol by means of the Guggenheim method as previously described.[21] For the purpose of calibration, the rate constant for α-phenylethyl chloride was measured at 50.0 °C and compared with Winstein's;[22] our result (16.3×10^{-5}, s^{-1}) agreed to within 4%. The rates of **1** and **2** were measured at 45.0 °C. A single batch of solvent was used for all experiments. In each of these, 5 mg of substrate was dissolved in 25 mL, and the solution was transferred to the conductance cell, and this was suspended in a thermostatted high-pressure vessel.[14] The resistance was measured periodically to at least 99% reaction.

Product Analysis. Remaining samples of **1** and **2** were methanolyzed at atmospheric pressure and at 600 MPa. The product solutions in each case were treated with 2 mg of 5% palladium on carbon catalyst and hydrogenated with 2 atm of hydrogen pressure in a hydrogenation apparatus for about 2 h. After filtration of the catalyst, the solvent was evaporated to yield residues that were analyzed by means of GC–MS.

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Asymmetric Synthesis of the Methyl and Benzyl Ethers of *erythro*-α,β-Diphenyl-β-hydroxyethanol and *erythro*-α,β-Diphenyl-β-hydroxyethylamine from (+)-(*S*)-Benzoin

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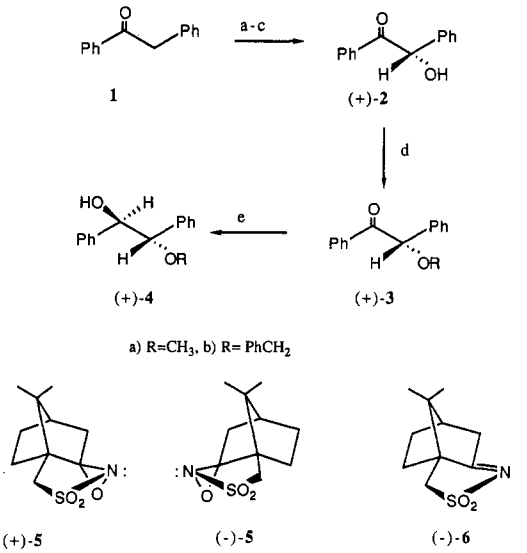
In connection with our interest in the synthesis and application of optically active α-hydroxy acids we needed to prepare the methyl and benzyl ethers of *erythro*-α,β-diphenyl-β-hydroxyethanol, **4a** and **4b**, respectively.[1-3] These compounds were required as chiral auxiliaries in studies of double asymmetric synthesis for the asymmetric oxidation of chiral enolates to α-hydroxy carbonyl compounds with (camphorylsulfonyl)oxaziridine (+)-**5** and (−)-**5**.[1] This protocol has recently been demonstrated in the enantioselective synthesis of atrolactic acid (88–91% ee).[1]

Scheme I[a]



[a] (a) NaHMDS, THF, −78 °C; (b) (+)-**5**, NH_4I; (c) $(CF_3CO)_2O$, 5% NaOH; (d) Ag_2O, MeI, $CHCl_3$ or benzyl trichloroacetimidate; (e) DIBAL-H, THF, −78 °C.

Our synthetic strategy is outlined in Scheme I and begins with the preparation of enantiomerically pure (+)-(*S*)-benzoin (**2**). This compound can be prepared in >96% optical purity and 84% isolated yield by oxidation of the sodium enolate of deoxybenzoin (**1**) with (+)-(2*R*,8a*S*)-(camphorylsulfonyl)oxaziridine (**5**).[2] On a small scale (0.5 mmol) (+)-**2** is separated from the sulfonimine **6** byproduct by preparative TLC or flash chromatography. To avoid the chromatographic separation on a larger scale synthesis of (+)-**2** (50 mmol) the hydroxyl group is transformed into the triflate ester by treatment of the crude reaction mixture with trifluoroacetic anhydride. The triflate ester was separated from the polar sulfonimine (−)-**6** by extraction into *n*-pentane. Hydrolysis of the triflate ester with 5% NaOH gives **2** in 67% overall yield from **1**. Attempts to remove the triflate ester with dilute HCl resulted in racemization. Recrystallization from ethanol increases the optical purity of (+)-**2** from 96% ee to 98% ee as determined by HPLC with a chiral column.

Routes to enantiomerically pure (+)-**2** and (−)-**2** include resolution,[4] enzymatic reduction of benzil,[5] and oxidation of optically active ethyl 2-amino-1,2-diphenylacetate.[6] This asymmetric enolate oxidation approach to (+)-benzoin (**2**) (+)-**2** is particularly efficient since (+)-**5** is readily available.[7] An additional advantage of this methodology is that both (+)-**2** and (−)-**2** can be easily prepared because the configuration of the oxaziridine three-membered ring in (+)-**5** and (−)-**5** controls the product stereochemistry.[7]

The alkylation of enolates derived from α-hydroxy ketones with carbon electrophiles is reported to occur at the carbon atom bearing the hydroxy group.[8] Indeed, at-

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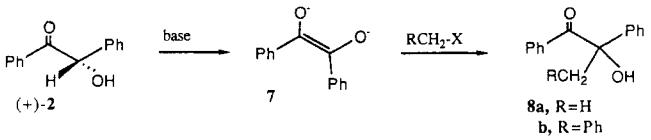
Table I. Metal Hydride Reduction of (+)-2-Methoxy-1,2-diphenylethanone (3a)

entry	reducing agent	solvent; temp, °C	time, h	% yield[a]	erythro/threo[b]
1	$LiAlH_4$	THF; 0	5	82	93.5:6.5
2		THF; −78	1	85	95:5
3		THF/HMPA;[c] 0	5	82	90.4:9.6
4		Et_2O; 0	0.5	84	97:3
5		Et_2O; −78	1	83	98:2
6	DIBAL-H	toluene; −78	2.5	78[d]	87:13
7		THF; −78	2.5	85	99:1
8	$NaBH_4$	$MeOH/H_2O$; 0	0.5	86	90:10
9	K-Selectride	THF; −78	1	79	98:2
10		Et_2O; −78	3	68	99:1
11	$PhSi(Me_2)H$ Bu_4NF[e]	HMPA; 25	32	0[f]	
12	H_2/Pd[g]	EtOH; 25	5	98	76:24

[a] Isolated yields. [b] Ratio determined by GLC and ^1H NMR analysis. A 6 ft × $^1/_8$ in., 3% OV-17 column. [c] THF:HMPA ratio was 9:1. [d] 15% starting material was recovered. [e] Tetra-*n*-butylammonium fluoride was used as a catalyst. [f] More than 80% starting material was recovered. [g] Racemic **3a** was used.

tempts to prepare the methyl and the benzyl ethers, **3a** and **3b**, respectively, by treating the crude sodium salt of (+)-**2** with methyl iodide and benzyl bromide gave C-alkylation products **8a** and **8b** in 25 and 45% yield, respectively. In addition to satisfactory elemental analysis, **8a–b** exhibits OH stretching at 3380–3460 cm^{-1} in the infrared spectra and broad OH absorption at δ 4.8–4.08 ppm in the proton NMR spectra. Racemization occurred in the process. It is likely that enediolate **7** is involved in these transformations. The deracemization of (±)-**2** by the enantioselective protonation of enediolate **7** to give optically active **2** (80% ee) has been described.[8c]



The desired methyl ether (+)-**3a** was prepared in quantitative yield by treating (+)-**2** with silver oxide and methyl iodide according the procedure of Garden and Thomson.[9] The method of Widmer was used to prepare the benzyl ether (+)-**3b**, in 72% yield from (+)-**2** and benzyl 2,2,2-trichloroacetimidate.[10] The infrared spectra of ethers (+)-**3a** and (+)-**3b** lacked hydroxyl absorption and the PhC*H* protons appeared as singlets at δ 5.5 and 5.65 ppm, respectively.

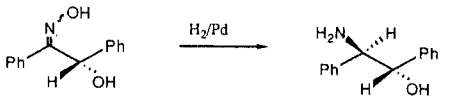
We next turned our attention to the synthesis of the methyl and benzyl ethers of α,β-diphenyl-β-hydroxyethanol **4** by reduction of **3**. Stereoselectivity in the reduction of chiral α-alkoxy ketones has been the subject of numerous studies.[11] Generally metal hydrides give good to excellent *erythro* selectivity, which can be predicted by either the open chain or chelated Cram models.[12] Results for the reduction of (+)-**3a** with metal hydrides are summarized in Table I.

In all cases the *erythro* diastereomer **4a** was the predominant product. With the exception of diisobutylaluminum hydride (DIBAL) reductions in toluene (entry 6), the *erythro* isomer was formed nearly exclusively. Both reduction with DIBAL in THF and K-Selectride (Aldrich) in ether gave an *erythro/threo* ratio of 99:1 (98% de) (entry 7 and 10). However, in the latter case about 15% of the starting ketone remained even after 5 h. It is interesting to note that reduction of (+)-**3a** with phenyldimethylsilane catalyzed by tetrabutylammonium fluoride failed (entry 11). This reagent is reported to give high *threo* selectivity in the reduction of α-alkoxy ketones.[11d] As expected low selectivity was observed for the hydrogenation of **3a** with a 5% Pd/C catalyst (entry 12). Similar high *erythro/threo* selectivity (>99:1) was observed for the DIBAL reduction of benzyl ether (+)-**3b**, affording (+)-**4b** (98% de) in 77% yield.

Some racemization of **4a–b** could occur if the corresponding enolates of **3a–b** were generated in the reduction. That racemization did not occur during the reduction step was confirmed by ^1H NMR spectroscopy with the chiral shift reagent $Eu(tfc)_3$.

The assignment of the *erythro* stereochemistry to the major isomer of **4a–b** is based on NMR studies of similar sets of diastereoisomers by Hiyama and Fujita.[11d] They observed that the PhC*H* proton of *erythro*-glycols exhibits absorption at δ 4.88 (d, J = 4 Hz) whereas the *threo* isomers exhibited absorption at δ 4.28 (d, J = 7 Hz). The major diastereoisomers in the reduction of **3a–b** to **4a–b** exhibited an absorption at δ 4.9 (d, J = 4.5 Hz) while the minor isomer appears at δ 4.6 (d, J = 7 Hz) ppm.

William and co-workers recently reported useful methodology for the asymmetric synthesis of α-amino acids using electrophilic 4*H*-1,4-oxazin-2-one glycine templates.[13] This template was prepared from (+)- and (−)-*erythro*-α,β-diphenyl-β-hydroxyethylamine (**10**), which was obtained in homochiral form by resolution.



A potentially useful route to (+)-**10** is the stereoselective reduction of oxime (+)-**9**, prepared from (+)-**2**. Previously, Harada and Shiono reported that the stereoselectivity for the catalytic hydrogenation of **9** was dependent on the geometry of the ketoxime.[6] Indeed we found that the palladium-catalyzed hydrogenation of racemic **9** (E:Z = 63:37) gave a 86:14 *erythro/threo* mixture of **10**. However, when the hydrogenation of **9** (E:Z = 63:37) was carried out in ethanol containing 1.5% by weight HCl, the stereoselectivity proved to be nearly invariant of the oxime structure, affording greater than 93% of *erythro*-**10** in 69% isolated yield. Crystallization from benzene improved the optical purity to >98% ee. Hydrogenation of (+)-**9** (98.6% ee) afforded *erythro*-(+)-**10** >97% ee optically pure with the chiral shift reagent $Eu(tfc)_3$.

Attempts to reduce **9** with metal hydride reagents (LAH, $NaBH_4$, etc.) were generally unsuccessful, giving little if any reduction. This is probably due to initial formation of the ketoxime anion, which inhibits further reduction. However, reduction of **9** in *tert*-butyl alcohol with the

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(10) Widmer, U. *Synthesis* **1987**, 568.

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combination of $NaBH_4$ and $NiCl_2$, as reported by Ipaktschi,[14] gave an *erythro/threo* (83:17) mixture of **10** in 54% yield.

In summary, the methyl and benzyl ethers of (+)-*erythro*-α,β-diphenyl-β-hydroxyethanol are prepared in two steps from (*S*)-(+)-benzoin (**2**). Asymmetric oxidation of the sodium enolate of deoxybenzoin (**1**) with (+)-(camphorylsulfonyl)oxaziridine (**5**) affords enantiomerically pure (*S*)-(+)-benzoin (**2**) in good yield. Catalytic hydrogenation of benzoin oxime (+)-**9**, in the presence of acid, affords (+)-*erythro*-α,β-diphenyl-β-hydroxyethylamine (**10**) in high optical purity.

Experimental Section

^1H NMR spectra were obtained at 250 MHz. Thin-layer chromatographs were accomplished with Analtech Uniplate, Silica Gel Gf, 1000 μm precoated TLC plates. Analytical HPLC analyses of (+)-**2** were performed on a Varian 5000 liquid chromatograph with a Daicel OT(+) Chiral-Pak column as previously described.[3]

(+)-(*S*)-Benzoin (2). Freshly distilled THF, 250 mL, was placed in a 1-L three-necked round-bottomed flask fitted with an argon gas bubbler, a 200 mL dropping funnel, a rubber septa, and a magnetic stirring bar. The reaction mixture was cooled to −78 °C in a dry ice/acetone bath, and 88 mL of sodium bis(trimethylsilyl)amide (Aldrich) (66 mmol, 0.75 M in THF) was added via syringe followed by dropwise addition of a solution of 10.0 g (51 mmol) of deoxybenzoin (**1**) in 100 mL of dry THF. After the mixture was stirred for 30 min, a solution of 17.5 g (77 mmol) of (+)-(2*R*,8a*S*)-(camphorylsulfonyl)oxaziridine (**5**)[7] in 150 mL of THF was added dropwise over a period of 20 min. The dark violet reaction mixture was stirred for 15 min, and 25 g (119 mmol) of trifluoroacetic anhydride was added via syringe. The reaction mixture was allowed to attain room temperature, the dropping funnel was replaced by a reflux condenser, and the solution was heated at reflux for 2 h. After cooling, the reaction mixture was quenched by addition of 25 mL of saturated ammonium iodide, and the volume was reduced to about 200 mL with a rotary evaporator. The solution was diluted with 400 mL of ether and washed successively with 0.1 N sodium thiosulfate solution (75 mL × 2), saturated sodium bicarbonate solution (75 mL × 5), 1% cold sulfuric acid (75 mL), and saturated brine (60 mL). After the mixture was dried over anhydrous $MgSO_4$, the solvent was removed in rotary evaporator.

The crude product was extracted with *n*-pentane (10 × 50 mL), and the combined extracts were diluted with an addition 200 mL of *n*-pentane. After filtering, the solvent was removed to give 15.0 g of the crude triflate ester: ^1H NMR ($CDCl_3$) δ 8.00–7.85 (m, 2 H), 7.60–7.32 (m, 8 H), 6.98 (s, 1 H). The residue consisted of 11.8 g (72%) of camphorsulfonyl imine (**6**).[7] The crude triflate ester was dissolved in 100 mL of methylene chloride and cooled to 5 °C, and 125 mL of 5% NaOH solution was added slowly. After being stirred for 45 min, the reaction mixture was transferred into an 1-L separatory funnel, diluted with 50 mL of THF and 250 mL of ether, and washed successively with water (2 × 50 mL), 1% cold sulfuric acid (2 × 50 mL), and brine (60 mL). After drying ($MgSO_4$), the solvent was removed to give 11.6 g of crude material consisting of 75% **2** and about 10% **1** by GLC. Recrystallization of the crude product from pentane-ethanol gave 7.3 g (67.5% from deoxybenzoin) in two crops. Crystallization from ethanol gave (+)-(*S*)-benzoin (**2**): mp 135 °C; $[\alpha]_D$ +114.9° (*c* 1.5, acetone) [lit.[4] $[\alpha]_D$ 118.4° (c 2.4, acetone)]. The optical purity was determined to be >97.7% ee by HPLC with a Daicel Chiral Pak OT(+) HPLC column, 25 cm × 0.46 cm; solvent MeOH; flow rate 0.5 mL/min. First to be eluted was (+)-(*S*)-benzoin (**2**).[2]

(+)-(*S*)-Methoxy-1,2-diphenylethanone (3a). (+)-(*S*)-Benzoin (**2**), 1.5 g (7.1 mmol), was refluxed with 3 g of silver oxide and 3 mL of methyl iodide in 35 mL of chloroform according to the procedure of Garden and Thomson.[9] After 20 h an additional 1 g of silver oxide and 1 mL of methyl iodide were added, and the reaction mixture was refluxed for an additional 4 h. The reaction mixture was decolorized by addition of 1.0 g of activated charcoal and filtered through a 1-in. $MgSO_4$ bed in a 100-mL sintered-glass funnel. The solvent was removed to give 1.6 g (100%) of **3a**: mp 50–51 °C (lit.[15] mp 53–4 °C); ^1H NMR ($CDCl_3$) δ 8.05–7.9 (m, 2 H), 7.55–7.25 (m, 8 H), 5.53 (s, 1 H), 3.48 (s, 3 H, Me); IR (KBr) 1690 (C=O), 1600, 1580, 1490, 1450 cm^{-1}; $[\alpha]_D$ +83° (*c* 2.5 $CHCl_3$) (lit.[16] for (+)-(*R*)-**3a** $[\alpha]_D$ −88.2°).

(+)-(*S*)-2-Benzoxy-1,2-diphenylethanone (3b). (+)-(*S*)-Benzoin (**2**), 0.2 g (0.94 mmol), in 8 mL of cyclohexane and 4 mL of methylene chloride was treated with 0.51 g (2.2 mmol) of the benzyl 2,2,2-trichloroacetimidate and 2 drops of trifluormethanesulfonic acid according to the procedure of Widmer.[10] After the reaction mixture was stirred for 60 h, the solution was filtered through $MgSO_4$, diluted with 20 mL of ether, and washed with 10 mL of sodium acetate solution and 10 mL of brine. After drying ($MgSO_4$), the solvent was removed, and crude **3b** was purified by preparative TLC (silica gel), eluting with 25% ether–hexane, to give 0.2 g (72%) of **3b** and 0.3 g (15%) of **2**. **3b**: ^1H NMR ($CDCl_3$) δ 8.05–7.90 (m, 2 H), 7.60–7.25 (m, 13 H), 5.68 (s, 1 H), 4.66 (s, 2 H); IR (neat) 1690 (C=O), 1595, 1580, 1492, 1450 cm^{-1}; $[\alpha]_D$ +14.75° (*c* 4, $CHCl_3$). Anal. Calcd for $C_{21}H_{18}O_2$: C, 83.42; H, 6.00. Found: C, 83.52; H, 5.96.

2-Hydroxy-1,2-diphenyl-1-propanone (8a). A solution of 1.9 mL (1.4 mmol) of sodium bis(trimethylsilyl)amide (Aldrich) in 8 mL of dry THF, under argon, was cooled to −78 °C. A solution of 0.2 g (1 mmol) of deoxybenzoin (**1**) in 5 mL of THF was added dropwise, followed after 30 min by of 0.37 g (1.6 mmol) of (+)-(camphorylsulfonyl)oxaziridine (**5**), in 6 mL of THF. After 15 min, 0.7 g (4.9 mmol) of iodomethane in 4 mL of THF was added, and the reaction mixture was refluxed for 4 h. After the mixture was cooled to room temperature, 1 mL of a saturated solution ammonium iodide was added followed by 30 mL of ether. The organic phase was washed with 20 mL of 0.1 N sodium thiosulfate and 20 mL of brine. After drying ($MgSO_4$), the solvent was evaporated, and the residue was purified by preparative TLC to give 0.057 g (25%) of **8a**: mp 64–5 °C (CH_2Cl_2); IR (neat) 3460 (broad, OH), 1680 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 8.05–7.25 (m, 10 H), 4.80 (br s, 1 H, exchange with D_2O), 1.9 (s, 3 H, Me); MS, *m/e* (relative abundance) 226 (M^+, 5.2), 209 (M − OH, 17) 121 (75), 105 (50) 77 (100). Anal. Calcd for $C_{15}H_{14}O_2$: C, 79.62; H, 6.23. Found: C, 79.88; H, 6.29.

2-Hydroxy-1,2,3-triphenyl-1-propanone (8b). The same procedure was followed as described for the preparation of **8a**, except that 0.5 mmol (50%) excess of benzyl bromide was used, and the mixture was stirred at room temperature for 15 min. Preparative TLC (silica gel) gave 0.14 g (45%) of **8b**: mp 115–6 °C (lit.[8b] mp 115–116 °C); IR (KBr) 3380 (broad, OH), 1680 (C=O) cm^{-1}; NMR ($CDCl_3$) δ 7.75–6.90 (m, 15 H), 4.08 (s, 1 H, D_2O exchange), 3.82–3.42 (q, *J* = 9 Hz, 2 H). Anal. Calcd for $C_{21}H_{18}O_2$: C, 83.42; H, 6.00. Found: C, 83.46; H, 6.05.

***erythro*-α,β-Diphenyl-β-hydroxyethanol Methyl Ether (4a). Reduction with $LiAlH_4$ or $NaBH_4$.** A suspension of 0.05 g (1.3 mmol) of lithium aluminum hydride in 3 mL of dry THF or a solution of 0.05 g (1.3 mmol) of sodium borohydride dissolved in 1.5 mL of methanol and 1.5 mL of water was cooled to 0 °C in an ice bath, and 0.057 g (0.25 mmol) of methyl ether **3a** in 3 mL of THF or 1.5 mL of methanol was added. After being stirred for 30 min, the reaction mixture was quenched by addition of 0.5 mL of 5% NaOH solution. The LAH reduction was filtered through a 0.5-in. bed of anhydrous $MgSO_4$ and then washed with 10 mL of ethyl ether. The $NaBH_4$ reduction was diluted with 20 mL of ether, washed with 3 × 10 mL of water, 2 × 10 mL of 1 N HCl solution, and 10 mL of brine followed by drying over anhydrous $MgSO_4$.

Reduction with K-Selectride. In a similar experimental apparatus was placed 0.057 g (0.25 mmol) of **3a** dissolved in 3 mL of dry THF or ethyl ether and cooled to −78 °C. Potassium tri-*sec*-butylborohydride (K-Selectride), 0.75 mL (0.75 mmol), was added dropwise, and the reaction mixture was stirred for 1 h (or 3 h when ether was the solvent). The reaction mixture was quenched by addition of 0.5 mL of water, diluted with 20 mL of ether, and warmed to 0 °C. Sodium hydroxide, 0.5 mL of a 10% solution, was cautiously added followed by 2 mL of 30% hydrogen peroxide. The mixture was transferred to a separatory funnel, washed with 10 mL of water, 10 mL of 2% sulfuric acid, and 10

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(15) Wren, H. *J. Chem. Soc.* **1909**, *95*, 1583.

mL of brine, and dried over anhydrous $MgSO_4$.

Crude **4a**, obtained by using the different reducing agents, was purified by preparative TLC (silica gel) with 20% ether in hexane as eluant to obtain **4a**. Compound (+)-**4a** was crystallized from *n*-hexane: mp 99 °C; IR (KBr) 3430 cm^{-1} (broad, OH); ^1H NMR ($CDCl_3$) δ 7.40–7.10 (m, 10 H), 4.94 (d, J = 4.5 Hz, *erythro* PhCH), 4.35 (d, 1 H, J = 4.5 Hz *erythro* (PhCH), 3.26 (s, 3 H, *erythro* MeO), 2.6 (br s, 1 H, OH); $[\alpha]_D$ +23.4° (*c* 1.6, $CHCl_3$); EI-MS, *m/z* (relative intensity) 228 (M^+) 211 (M^+ - OH, 1), 121 (100), 91 (7), 77 (14).

threo Isomer: ^1H NMR ($CDCl_3$) δ 4.6 (d, 1 H, J = 7 Hz, *threo* PhCH), 3.34 (s, 3 H, *threo* MeO). Anal. Calcd for $C_{15}H_{16}O_2$: C, 78.71; H, 7.06. Found: C, 78.71; H, 7.08.

Reduction with DIBAL. A solution of 0.438 g (1.94 mmol) of **3a** in 15 mL of dry THF was cooled to −78 °C under nitrogen. DIBAL in hexane, 5.8 mL (5.8 mmol), was added to the reaction mixture via syringe, and the mixture was stirred for 2 h. After being quenched by cautious addition of 3 mL of water, the reaction mixture was diluted with 20 mL of ether, transferred to a separatory funnel, washed with 1 N HCl (2 × 10 mL) and 10 mL of brine, and dried over anhydrous $MgSO_4$. After removal of the solvent the crude **4a** was crystallized from *n*-hexane to give 0.380 g (85%) of (+)-**4a**, mp 99–100 °C.

(+)-*erythro*-α,β-Diphenyl-β-hydroxyethanol Benzyl Ether (4b). As described above 0.080 g (0.265 mmol) of **3b** in 5 mL of THF was reduced with 0.8 mL (0.8 mmol) of DIBAL in *n*-hexane at −78 °C. After the reaction was quenched by addition of 1 mL of water, the mixture was diluted with 10 mL of ether, transferred to a separatory funnel, washed with 1 N HCl (2 × 5 mL) and 5 mL of brine, and dried over anhydrous $MgSO_4$. Removal of the solvent gives 0.063 g (77%) of **4b**, which is crystallized from *n*-hexane: mp 59 °C; IR (neat) 3420 (OH) cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.45–7.05 (m, 15 H), 4.92 (d, J = 5 Hz, erythro PhCH), 4.58–4.15 (m, 3 H), 2.25 (br s, 1 H); $[\alpha]_D$ +23.7° (*c* 1.9, $CHCl_3$).

threo Isomer: ^1H NMR ($CDCl_3$) δ 7.5–6.9 (m, 15 H, 4.67 (d, 1 H, J = 7 Hz, *threo* PhCH), 3.34. Anal. Calcd for $C_{21}H_{20}O_2$: C, 82.87; H, 6.62. Found: C, 82.64; H, 6.65.

(+)-(*S*)-Benzoin Oxime (9). To 0.4 g (5.76 mmol) of hydroxylamine hydrochloride were added 0.8 g (5.87 mmol) sodium acetate and 0.5 g (2.36 mmol) of (+)-(*S*)-benzoin (**2**) in 15 mL of ethanol. Enough water (3 mL) to dissolve the solids was added, and the solution was heated at reflux for 20 min. After the mixture was cooled to room temperature, 25 mL of water was added, and the flask was placed in an ice bath. After 20 min, the white crystals were collected and air-dried to give 0.5 g (90%) of (+)-(*S*)-benzoin oxime (**9**) as a 63:37 *E*:*Z* mixture, determined by ^1H NMR:[16] mp 145–153 °C (lit.[17] mp 163 °C); ^1H NMR ($CDCl_3$) δ 7.55–7.2 (m, 10 H), 6.2 (s, PhC*H*, 0.37 H, *Z* isomer), 5.59 (s, 0.63 H, *E* isomer), 3.7 (br s, 1 H, OH); $[\alpha]_D$ +2.6° (*c* 0.5, $CHCl_3$) [lit.[6] $[\alpha]_D$ +3.2° (*c* 0.5, $CHCl_3$) of the (−)-(*R*)-(*E*)-**9**].

(+)-*erythro*-α,β-Diphenyl-β-hydroxyamine (10). (+)-(*S*)-Benzoin oxime (**9**), 0.5 g (2.2 mmol), was hydrogenated over 5% Pd/C catalyst in 10 mL of ethanol containing 1.5% HCl for 7 h according to the procedure of Tishler et al.[17] to give 0.32 g (69%) of **10**: mp 135–6 °C (lit.[13] mp 143 °C); HCl salt, mp 208–209 °C (lit. mp 210–212 °C); $[\alpha]_D$ +66.8° (*c* 0.5, $CHCl_3$) [lit.[13] $[\alpha]_D$ +69.6° (*c* 0.65, H_2O)]; ^1H NMR ($CDCl_3$) δ 7.35–7.15 (m, 10 H), 4.75 (d, 2 H, J = 5 Hz), 4.15 (d, 1 H, J = 5 Hz), 2.1–1.6 (br s, 3 H, OH, NH_2).

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Registry No. **1**, 451-40-1; (+)-**2**, 5928-67-6; (+)-**2** trifluoroacetate, 118298-90-1; (+)-**3a**, 82572-27-8; (±)-**3a**, 5987-95-1; (+)-**3b**, 118298-91-2; (+)-**4a**, 118353-44-9; **4a** threo isomer, 118353-46-1; (+)-**4b**, 118298-93-4; **4b** threo isomer, 118298-94-5; (+)-**5**, 104322-63-6; (−)-**6**, 60886-80-8; **8a**, 118298-89-8; **8b**, 118298-92-3; (+)-**9** E isomer, 118353-45-0; (+)-**9** Z isomer, 118353-47-2; (+)-**10**, 23364-44-5; sodium bis(trimethylsilyl)amide, 1070-89-9; benzyl trichloroacetimidate, 81927-55-1; benzyl bromide, 100-39-0.

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Structural Studies on the Product of Heterocyclization of 2,5-Dimercapto-1,3,4-thiadiazole with 1,3-Dibromopropane: A Revision

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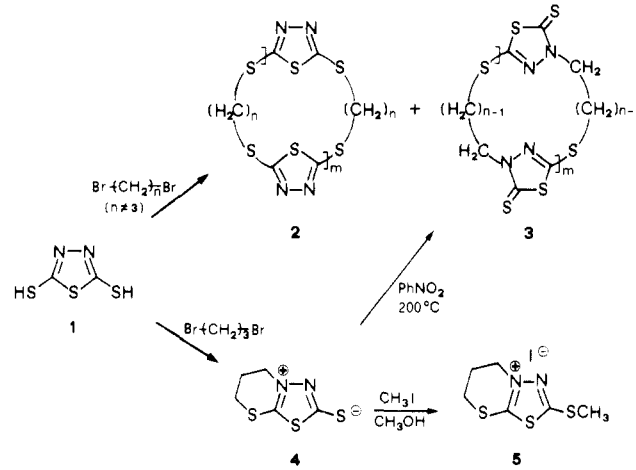
We have been interested in the synthesis and stereochemical behavior of medium-sized S-bridged metacyclophanes[1] and heterophanes.[2] Their conformational aspects in solution have been well-studied via the convenient ^1H NMR spectral probes present in the form of "internal" protons or substituents.[3]

Recently, we have shown that the high-dilution heterocyclization of 2,5-dimercapto-1,3,4-thiadiazole (**1**) with 1,ω-dibromoalkanes $Br(CH_2)_nBr$ (n = 1–4) in alkaline medium offers a practical route to polythia[$(n + 2)_m$]-(2,5)-1,3,4-thiadiazolophanes **2** and/or [$(n + 1)_m$](3,5)-1,3,4-thiadiazolinophanethiones **3**. Since heterophanes **2** and **3** lack the above ^1H NMR spectral probes, single-crystal X-ray structure determinations on the products of heterocyclization of **1** with 1,3-dibromopropane (n = 3) and 1,4-dibromobutane (n = 4) have been conducted in order to establish their solid-state conformations. With the aid of this study, the revised structure (**4**) is now reported for the former product.



Results and Discussion

The structural data of **2** (m = 1; n = 4) have been already reported.[5] Quite surprisingly, structural analysis on the product of the reaction of the dipotassium salt of **1** with 1,3-dibromopropane has shown it to be the monomer **4**, not the dimer **3** (m = 1; n = 3). Coordinates of **4** are given in Table I, and the molecule is illustrated in Figure 1. The molecule lies on a mirror plane, with the atoms C(4) and C(5) of the six-membered thiazine ring disordered into half-populated positions related by the mirror. Except for the disordered C atoms, the molecule is exactly planar, and all molecules pack in parallel fashion in the crystal.

The molecule is characterized as a zwitterion on the basis of the planarity of the heterocyclic thiadiazole ring and

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