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# Synthesis of enantiomerically enriched β-hydroxy selenides by catalytic asymmetric ring opening of *meso*-epoxides with (phenylseleno)silanes

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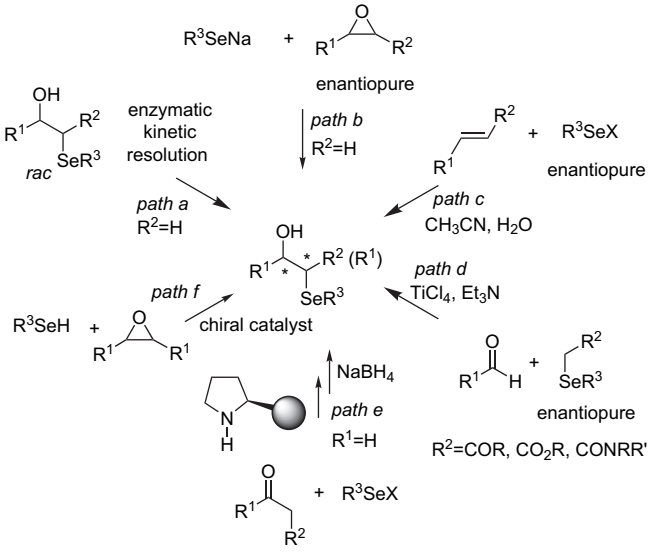
**Abstract**

The first example of the enantioselective ring opening of *meso*-epoxides by (phenylseleno)silanes using salen(Cr)complexes as catalyst is described. This desymmetrization reaction constitutes a simple and convenient approach to synthetically versatile optically active β-hydroxy selenides.


*Keywords:* Desymmetrizations; Enantioselective synthesis; Organoselenium compounds; *meso*-Epoxides

## 1. Introduction

β-Hydroxy selenides are useful intermediates for a variety of synthetic transformations. Together with classical reactions, such as the reductive deselenenylation to alcohols[1] or the oxidation to allylic alcohols,[1] simple and convenient conversions into tetrahydrofurans,[2] 1,3-oxazolidinones,[3] amino alcohols,[3] and β-aryl-selenides[4,5] have been recently reported in the literature. In view of their large synthetic utilization, several approaches to enantiomerically enriched β-hydroxy selenides with different skeleton and stereochemical requirements have been developed. The most common procedures (Scheme 1) are the lipase-promoted kinetic resolutions of racemic β-hydroxy selenides (*path a*),[6] the regio and stereospecific ring opening of commercial enantiopure epoxides by arylselenolates[1] (substrate-controlled asymmetric syntheses, *path b*), the asymmetric seleno-hydroxylation of alkenes promoted by enantiomerically pure electrophilic selenium reagents,[7] and the asymmetric aldol reactions with enantiomerically pure α-seleno ketones, esters, or amides[8] (reagent-controlled asymmetric syntheses, *path c* and *path d*).




Scheme 1. Preparation of optically active β-hydroxy selenides.

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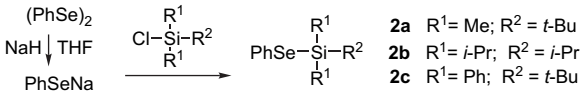
Catalyst-controlled asymmetric syntheses have been scarcely investigated. Very recently, we have prepared β-hydroxy selenides in excellent enantiomeric purity by the chiral amine catalyzed α-selenenylation of aldehydes followed by in situ reduction (*path e*).[9] β-Hydroxy selenides with two contiguous chiral centers have been prepared by the enantioselective ring opening of *meso*-epoxides with benzeneselenol in the presence of the heterobimetallic salen Titanium–Gallium complex (*path f*).[10] We now report the first desymmetrization of *meso*-epoxides by (phenylseleno)silane **2a** and commercial or easily accessible salen catalysts.[11] This nucleophilic selenium source is more easy to handle than the easily oxidizable and malodorous benzeneselenol.

## 2. Results and discussion

The (phenylseleno)silanes **2a–c** employed for the present investigation were prepared by analogy with the procedures described in the literature as indicated in Scheme 2.[12] These compounds can be purified by distillation or crystallization and stored for several days without particular precautions.



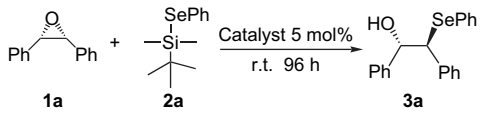

Scheme 2. Preparation of the (phenylseleno)silanes **2a–c**.

Preliminary experiments were performed, at room temperature and under air atmosphere, on stilbene oxide **1a** in order to evaluate the efficiency of the selenium reagents **2a–c**[13] and of several (*R*,*R*)-salen(metal)complexes in different solvents (0.5 M solutions). The best results in terms of yield and er were obtained using the *tert*-butyl(dimethyl)(phenylseleno)silane **2a**. Under the same reaction conditions **2b** gave similar er, but considerably poorer yields, and **2c** was ineffective. The results of several selected experiments carried out with **2a** are reported in Table 1. The best results in terms of yield and enantiomeric ratio were obtained with salen(Cr)$BF_4$ in *tert*-butylmethyl ether (entry 9).

Further optimization of the reaction was then attempted. The effects of the temperature and the addition of 1 equiv of *tert*-butanol,[1] tetrabutylammonium fluoride,[14] or tetramethylethylendiamine (TMEDA),[15] as activating agents for the silylated organoselenium reagents, have been investigated (entries 10–13). The results of these experiments indicate that the use of a low temperature and TMEDA as additive can dramatically improve the yield and the selectivity of the reaction (entry 11). In this case **3a** was obtained with 92% yield and 96:4 er. These results are considerably better than those previously reported.[10] Further improvements were not observed by using 10% of the catalyst, more concentrated solutions (2 M), or lower reaction temperatures.

The stereochemical attribution of compound **3a** was effected by reductive deselenenylation with tributyltin hydride and AIBN in refluxing toluene. The 1,2-diphenylethanol thus obtained has the *R* configuration as demonstrated

Table 1
Asymmetric ring opening of stilbene oxide **1a**: optimization of the reaction conditions




**1a** **2a** **3a**

| Entry | Catalyst | Temperature | Solvent (additive) | Yield[a] (%) | er[b] |
|---|---|---|---|---|---|
| 1 | Salen(Ti)($O^iPr$)$_2$ | RT | Hexane | 46 | 64:36 |
| 2 | Salen(Zn) II | RT | Hexane | 69 | 50:50 |
| 3 | Salen(Cr)$SbF_6$ | RT | TBME | 73 | 69:31 |
| 4 | Salen(Cr)Cl | RT | Hexane | 69 | 82:18 |
| 5 | Salen(Cr)Cl | RT | Toluene | 60 | 77:23 |
| 6 | (Salen)CrCl | RT | TBME | 60 | 63:37 |
| 7 | Salen(Cr)$BF_4$ | RT | Hexane | 60 | 84:16 |
| 8 | Salen(Cr)$BF_4$ | RT | Toluene | 67 | 89:11 |
| 9 | Salen(Cr)$BF_4$ | RT | TBME | 82 | 89:11 |
| 10 | Salen(Cr)$BF_4$ | RT | TBME (TMEDA) | 99 | 73:27 |
| 11 | Salen(Cr)$BF_4$ | −10 °C | TBME (TMEDA) | 92 | 96:4 |
| 12 | Salen(Cr)$BF_4$ | −10 °C | TBME (*t*-BuOH) | 99 | 77:23 |
| 13 | Salen(Cr)$BF_4$ | −10 °C | TBME ($Bu_4NF$) | 35 | 87:13 |

[a] Yields determined on isolated compounds after column chromatography.
[b] Enantiomeric ratios determined by HPLC on a Chiralpack AD-H column.

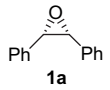
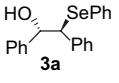
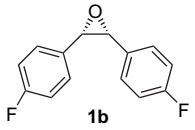
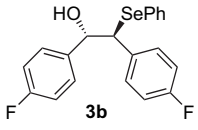
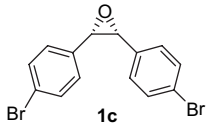
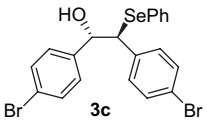
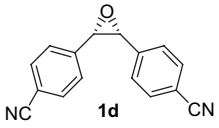
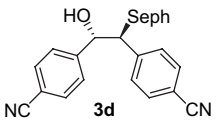
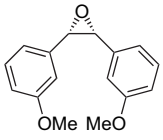
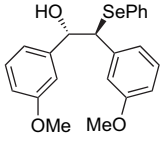
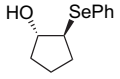
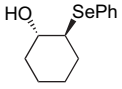
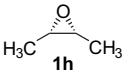
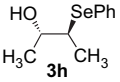
by the comparison of the specific optical rotation with that reported in the literature.[16] Considering that **3a** is formed with complete *anti* diastereoselectivity it can be confidently assumed that **3a** has the absolute configuration as indicated in Table 1.

We next examined the scope of this ring opening reaction by carrying out the desymmetrization reactions on other *meso*-epoxides. The epoxides **1f–h** are commercially available. The aryl epoxides **1b–e** were prepared[17] from substituted benzyl iodides and appropriate commercial benzaldehydes via Wittig reactions. The crude alkenes were submitted to epoxidation with *m*-CPBA without purification. *cis*-Epoxides, which under the reaction conditions employed are the major or the sole reaction products, were obtained in pure form after column chromatography.

The results of the desymmetrization experiments of the epoxides **1b–h** are reported in Table 2. The results obtained on stilbene oxide **1a** under optimized reaction conditions (method A) are also reported for comparison. The absolute configurations of compounds **3b–e** were assigned by analogy with **3a**, whereas those of compounds **3f–h** were attributed by comparison of the HPLC retention times (Chiralcel OD-H column) with those previously reported in the literature.[10]

In order to obtain good levels of enantioselectivity it was essential to use low reaction temperatures. Notably the enantioselectivity of the process depends on the structure of the starting epoxide. In fact, higher enantiomeric ratios were obtained with stilbene oxide **1a** and the *p*-substituted aryl epoxides **1b–d**. As already observed for **1a** the addition of TMEDA (method A) significantly improved the efficiency of the process in the cases of the aryl epoxides **1b–e** (entries 2–5). Cyclic or alkyl epoxides gave instead moderate to good results when TMEDA was not added (method B).

Table 2
Asymmetric ring opening of *meso*-epoxides **1a–h**

| Entry | Epoxide | Product | Temperature | Yield (%) | er |
|---|---|---|---|---|---|
| 1 |  **1a** |  **3a** | −10 °C | A 92 | 96:4 |
| 2 |  **1b** |  **3b** | −10 °C | A 50 | 85:15 |
| 3 |  **1c** |  **3c** | −10 °C<br>RT | A 53<br>A 31[a] | 86:14<br>72:28 |
| 4 |  **1d** |  **3d** | −10 °C<br>RT<br>RT | A 25[b]<br>A 70[b]<br>A 53[a,b] | 84:16<br>80:20<br>81:19 |
| 5 |  **1e** |  **3e** | −10 °C<br>RT<br>RT | A 50<br>A 94<br>A 34[a] | 75:25<br>66:34<br>64:36 |
| 6 |  **1f** |  **3f** | −10 °C<br>−10 °C | A 52<br>B 71 | 64:36<br>75:25 |
| 7 |  **1g** |  **3g** | −10 °C<br>−10 °C | A 70<br>B 88 | 67:33<br>81:19 |
| 8 |  **1h** |  **3h** | −10 °C | B 60 | 76:24 |

Method A: reactions carried out with salen(Cr)$BF_4$ of 5 mol % in TBME in the presence of 1 equiv of TMEDA for 96 h.
Method B: reactions carried out with salen(Cr)Cl of 5 mol % in $Et_2O$, without TMEDA for 96 h.
[a] Reaction carried out in the absence of TMEDA following method A.
[b] Reaction carried out in $CH_2Cl_2$ following method A.

## 3. Conclusions

In conclusion we have described the first enantioselective ring opening of *meso*-epoxides by (phenylseleno)silanes as nucleophilic selenium source and commercial or readily available salen(chromium) complexes as catalysts. These reactions constitute a simple and convenient approach to the synthetically versatile, optically active β-hydroxy selenides. The enantioselectivity of the process depends on the structure of the starting epoxide. Good to excellent results (up to 92% yield and 96:4 er) were obtained on stilbene epoxide and on its *p*-substituted derivatives in the presence of TMEDA as additive.[18] The results described in this paper nicely complement those obtained using benzeneselenol as the nucleophile, which were particularly efficient in the desymmetrization of cyclic or alkyl epoxides.

## 4. Experimental

### 4.1. General

New compounds were characterized by $^1H$, $^{13}C$ NMR, and mass spectra. $^1H$ and $^{13}C$ NMR spectra were recorded on a Bruker Avance-DRX 400 instrument (at 400 and 100.62 MHz, respectively) with $CDCl_3$ as solvent and TMS as internal reference. GC–MS analyses were carried out with an HP 6890 gas chromatograph (HP-5MS capillary column 30 m, ID 0.25 mm, film 0.25 μm) equipped with an HP 5973 Mass Selective Detector; for the ions containing selenium only the peaks arising from the selenium-80 isotope are given. HPLC analyses were performed on an HP 1100 instrument equipped with a chiral column and an UV detector.

Optical rotations were measured with a Jasco DIP-1000 digital polarimeter. Elemental analyses were carried out on a Carlo Erba 1106 Elemental Analyzer. Thin layer chromatography (TLC) was performed on silica gel 60 $F_{254}$ (Merck) on aluminum sheets. Column chromatography was performed using silica gel Merck 60 (70–230 mesh). For flash chrotography silica gel Merck 60 (230–400 mesh) was used.

### 4.2. Synthesis of the meso-epoxides

Epoxides **1a** and **1f–h** are commercial compounds (Aldrich). Epoxides **1b–e** have been prepared from substituted benzyl iodides and appropriate commercial benzaldehydes via a Wittig reaction followed by oxidation with *m*-CPBA according to the procedure described in the literature.[17] Intermediates have been employed without any purification. Chemical overall yields determined after purification by column chromatography, and physical and spectral data of compounds **1b–d** are reported below. GC–MS spectra of compounds **1b** and **1c** are not reported since these products suffered decomposition during the analysis. Compound **1e** has spectral properties identical to those previously described.[17]

#### 4.2.1. cis-2,3-Bis(4-fluorophenyl)oxirane (*1b*)

This compound was obtained in pure form (45% yield, 0.95 g) after flash chromatography (light petroleum to light petroleum/diethyl ether 96:4). Oil; $R_f$ 0.60 (light petroleum/diethyl ether 80:20); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.20–7.00 (m, 4H, Ph), 7.0–6.75 (m, 4H, Ph), 4.25 (s, 2H, CHO); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=162.1 (d, 2C, $^1J_{CF}$=244.3 Hz), 129.9 (2C), 128.4 (d, 4C, $^3J_{CF}$=8.0 Hz), 114.8 (d, 4C, $^2J_{CF}$=21.5 Hz), 59.0 (2C). Anal. Calcd for $C_{14}H_{10}F_2O$: C, 72.41; H, 4.34. Found: C, 72.54; H, 4.19.

#### 4.2.2. cis-2,3-Bis(4-bromophenyl)oxirane (*1c*)

This compound was obtained in pure form (36% yield, 0.9 g) after column chromatography (light petroleum to light petroleum/diethyl ether 90:10). White solid; mp=84–86 °C; $R_f$ 0.58 (light petroleum/diethyl ether 80:20); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.30–7.20 (m, 4H, Ph), 7.02–6.80 (m, 4H, Ph), 4.25 (s, 2H, CHO); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=133.0 (2C), 131.2 (4C), 128.5 (4C), 121.8 (2C), 59.2 (2C). Anal. Calcd for $C_{14}H_{10}Br_2O$: C, 47.50; H, 2.85. Found: C, 47.35; H, 2.78.

#### 4.2.3. cis-2,3-Bis(4-cyanophenyl)oxirane (*1d*)

This compound was obtained in pure form (30% yield, 0.7 g) after column chromatography (light petroleum/diethyl ether 70:30 to diethyl ether). White solid; mp=172–174 °C; $R_f$ 0.15 (light petroleum/diethyl ether 60:40); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.50–7.26 (m, 4H, Ph), 7.25–7.01 (m, 4H, Ph), 4.45 (s, 2H, CHO); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=138.4 (2C), 131.4 (4C), 126.9 (4C), 117.8 (2C), 111.5 (2C), 58.7 (2C); MS (70 eV, EI): *m/z* (%) 246 (100) [$M^+$], 217 (74), 190 (35), 130 (33), 115 (63), 88 (22). Anal. Calcd for $C_{16}H_{10}N_2O$: C, 78.03; H, 4.09; N, 11.38. Found: C, 77.87; H, 4.19; N, 11.50.

### 4.3. Synthesis of the (phenylseleno)silanes

(Phenylseleno)silanes **2a–c** were prepared according to the literature procedure.[12] Spectral data of compounds **2a** and **2c** are identical to those previously described. In the case of compound **2b** the by-products were removed by distillation under vacuum and the residue was sufficiently pure to be directly employed for the ring opening reactions. Physical and spectral properties of compound **2b** are reported below.

#### 4.3.1. Triisopropyl(phenylseleno)silane *2b*

Yield 40%, 1.4 g; yellow oil, slightly impure; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.70–7.65 (m, 2H, SePh), 7.30–7.14 (m, 3H, SePh), 1.36–1.28 (m, 3H, CH), 1.13 (d, 18H, $J$=7.4 Hz, $CH_3$); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=137.1 (2C), 128.6 (2C), 126.9, 124.7, 18.6 (6C), 13.2 (3C); MS (70 eV, EI): *m/z* (%) 314 (56) [$M^+$], 271 (100), 243 (14), 229 (53), 215 (13), 201 (40), 187 (20), 157 (30), 123 (24), 105 (34), 77 (28), 59 (31).

### 4.4. Catalysts

The (*R*,*R*)-salen(Cr)Cl is commercially available. The (*R*,*R*)-salen(Ti)($O^iPr$)$_2$,[11f] the (*R*,*R*)-salen(Zn)(II),[19] the (*R*,*R*)-salen(Cr)$BF_4$,[20] and the (*R*,*R*)-salen(Cr)$SbF_6$[21] have been prepared according to standard procedures.

### 4.5. Asymmetric ring opening of meso-epoxides: method A and method B

Method A: the *meso*-epoxides **1a–g** (0.5 mmol) and (*R*,*R*)-salen(Cr)$BF_4$ (0.025 mmol) were dissolved in TBME (0.5 M), and then **2a** (0.61 mmol) and TMEDA (0.5 mmol) were added. The resulting mixture was stirred for 96 h and then filtered *under vacuum* through a plug of silica gel with 30 mL of light petroleum/diethyl ether 70:30. The filtrate was concentrated and the crude mixture was analyzed by NMR. The crude β-hydroxy selenides **3a–g** were purified by flash chromatography.

Method B: the *meso*-epoxides **1f–h** were treated under the experimental conditions described for method A, but using salen(Cr)Cl as catalyst in $Et_2O$ and in the absence of TMEDA.

Physical and spectral data of **3f–h** are comparable with those reported in the literature.[10] Physical and spectral data of compounds **3a–e** are described below together with the eluant employed for the purification.

#### 4.5.1. (1S,2S)-1,2-Diphenyl-2-(phenylseleno)ethanol (*3a*)

This compound was obtained in pure form (92% yield, 165.6 mg) after flash chromatography (light petroleum to light petroleum/diethyl ether 90:10). Oil; $R_f$ 0.42 (light petroleum/diethyl ether 80:20); $[\alpha]_D^{23}$ +152.9 (*c* 3.1, $CHCl_3$); HPLC (Chiralpack AD-H (250×4.6 mm ID), eluant: hexane/$^i$PrOH 95:5, flow rate: 1 mL/min, UV detection at 230 nm), $t_R$: minor enantiomer 24.3 min, major enantiomer 30.2 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.48–7.44 (m, 2H, SePh), 7.30–7.20 (m, 11H, Ph, SePh), 7.03–6.99 (m, 2H, SePh), 5.08 (d, 1H,

$J$=8.8 Hz, CHO), 4.53 (d, 1H, $J$=8.8 Hz, CHSe), 3.40 (br s, 1H, OH); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=140.8, 139.9, 135.3 (2C), 128.9 (2C), 128.7, 128.4 (2C), 128.0 (4C), 127.9, 127.7, 127.0, 126.7 (2C), 76.6, 59.9. Anal. Calcd for $C_{20}H_{18}OSe$: C, 67.99; H, 5.14. Found: C, 68.21; H, 5.21.

### 4.5.2. (1S,2S)-1,2-Bis(4-fluorophenyl)-2-(phenylseleno)-ethanol (**3b**)

This compound was obtained in pure form (50% yield, 97.5 mg) after flash chromatography (light petroleum to light petroleum/diethyl ether 80:20). Oil; $R_f$ 0.65 (light petroleum/diethyl ether 60:40); $[\alpha]_D^{23}$ +110.5 ($c$ 1.1, $CHCl_3$); HPLC (Chiralpack AD-H (250×4.6 mm ID), eluant: hexane/$^i$PrOH 90:10, flow rate: 1 mL/min, UV detection at 230 nm), $t_R$: minor enantiomer 11.98 min, major enantiomer 13.29 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.35–7.25 (m, 2H, SePh), 7.25–7.0 (m, 5H, Ph, SePh), 6.90–6.70 (m, 6H, Ph), 4.92 (d, 1H, $J$=8.6 Hz, CHO), 4.30 (d, 1H, $J$=8.6 Hz, CHSe), 3.1 (br s, 1H, OH); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=162.2 (d, $^1J_{CF}$=244.8 Hz), 161.6 (d, $^1J_{CF}$=245.0 Hz), 136.2 (d, $^4J_{CF}$=3 Hz), 135.5 (2C), 135.3 (d, $^4J_{CF}$=3 Hz), 129.9 (d, 2C, $^3J_{CF}$=8.0 Hz), 129.0 (2C), 128.3 (d, 2C, $^3J_{CF}$=8.0 Hz), 128.2, 128.1, 115.0 (d, 4C, $^2J_{CF}$=21.3 Hz), 75.9, 58.7; MS (70 eV, EI): $m/z$ (%) 390 (<1), 266 (47), 233 (18), 216 (40), 201 (19), 185 (44), 158 (27), 137 (13), 123 (79) 109 (100), 95 (33), 77 (21), 51 (12). Anal. Calcd for $C_{20}H_{16}F_2OSe$: C, 61.70; H, 4.14. Found: C, 61.61; H, 4.28.

### 4.5.3. (1S,2S)-1,2-Bis(4-bromophenyl)-2-(phenylseleno)-ethanol (**3c**)

This compound was obtained in pure form (53% yield, 135.7 mg) after flash chromatography (light petroleum to light petroleum/diethyl ether 90:10). Oil; $R_f$ 0.44 (light petroleum/diethyl ether 80:20); $[\alpha]_D^{23}$ +42.0 ($c$ 1.1, $CHCl_3$); HPLC (Chiralpack AD-H column (250×4.6 mm ID), eluant: hexane/$^i$PrOH 90:10, flow rate: 0.75 mL/min, UV detection at 230 nm), $t_R$: minor enantiomer 21.41 min, major enantiomer 23.76 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.35–7.20 (m, 9H, Ph, SePh), 7.07–7.01 (m, 2H, Ph), 6.85–6.80 (m, 2H), 4.95 (d, 1H, $J$=8.7 Hz, CHO), 4.36 (d, 1H, $J$=8.7 Hz, CHSe), 3.30 (br s, 1H, OH); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=139.7, 138.6, 135.5 (2C), 131.2 (4C), 130.0 (2C), 129.0 (2C), 128.4 (2C), 128.3, 127.9, 121.7, 120.9, 75.5, 58.4; MS (70 eV, EI): $m/z$ (%) 355 (24) [$M^+$–PhBr], 326 (86), 281 (36), 247 (40), 207 (69), 185 (100), 169 (59), 155 (41), 139 (16) 118 (18), 91 (25), 77 (39), 63 (16). Anal. Calcd for $C_{20}H_{16}Br_2OSe$: C, 47.00; H, 3.16. Found: C, 47.12; H, 3.27.

### 4.5.4. (1S,2S)-1,2-Bis(4-cyanophenyl)-2-(phenylseleno)-ethanol (**3d**)

This compound was obtained in pure form (25% yield, 50.5 mg) after flash chromatography ($CH_2Cl_2$/MeOH 99:1 to $CH_2Cl_2$/MeOH 98:2). White solid; mp=113–117 °C; $R_f$ 0.49 ($CH_2Cl_2$/MeOH 98:2); $[\alpha]_D^{23}$ +43.5 ($c$ 1.0, $CHCl_3$); HPLC (Chiralpack AD-H column (250×4.6 mm ID), eluant: hexane/$^i$PrOH 75:25, flow rate: 0.75 mL/min, UV detection at 230 nm), $t_R$: minor enantiomer 17.53 min, major enantiomer 25.97 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.52–7.48 (m, 2H, Ph), 7.45–7.40 (m, 2H, Ph), 7.35–7.19 (m, 7H, Ph, SePh), 7.08–6.95 (m, 2H), 5.07 (d, 1H, $J$=8.3 Hz, CHO), 4.37 (d, 1H, $J$=8.3 Hz, CHSe), 3.50 (br s, 1H, OH); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=145.6, 144.8, 135.9 (2C), 132.1 (4C), 129.3 (2C), 129.0 (2C), 128.9, 127.4 (2C), 127.0, 118.4 (2C), 112.0, 111.2, 75.2, 58.4. Anal. Calcd for $C_{22}H_{16}N_2OSe$: C, 65.51; H, 4.00; N, 6.95. Found: C, 65.66; H, 4.17; N, 6.83.

### 4.5.5. (1S,2S)-1,2-Bis(3-methoxyphenyl)-2-(phenylseleno)-ethanol (**3e**)

This compound was obtained in pure form (50% yield, 103.5 mg) after flash chromatography (light petroleum to light petroleum/diethyl ether 70:30). Oil; $R_f$ 0.44 (light petroleum/diethyl ether 60:40); $[\alpha]_D^{23}$ +52.13 ($c$ 1.1, $CHCl_3$); HPLC (Chiralpack AD-H (250×4.6 mm ID), eluent: hexane/$^i$PrOH 90:10, flow rate: 1 mL/min, UV detection at 230 nm), $t_R$: major enantiomer 34.86 min, minor enantiomer 37.60 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=7.45–7.35 (m, 2H, SePh), 7.35–6.95 (m, 5H, Ph, SePh), 6.75–6.45 (m, 6H, Ph), 4.96 (dd, 1H, $J$=2.5, 8.6 Hz, CHO), 4.38 (d, 1H, $J$=8.6 Hz, CHSe), 3.64 (s, 3H, OMe), 3.60 (s, 3H, OMe), 2.66 (d, 1H, $J$=2.5 Hz, OH); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$=159.3, 159.2, 142.4, 141.4, 135.3 (2C), 129.1, 129.0, 128.9 (2C), 128.7, 128.0, 120.9, 119.2, 113.9, 113.5, 112.8, 112.1, 76.3, 59.7, 55.1 (2C); MS (70 eV, EI): $m/z$ (%) 278 (58), 240 (24), 227 (23), 207 (42), 195 (38), 165 (19), 149 (13), 135 (92), 121 (100) 107 (23), 91 (18), 77 (25). Anal. Calcd for $C_{22}H_{22}O_3Se$: C, 63.92; H, 5.36. Found: C, 63.79; H, 5.18.

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