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# Synthesis of 5-*ortho*-Carboranylsalicylaldehyde and an Indolinospirobenzopyran

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**Abstract:** 5-*ortho*-Carboranylsalicylaldehyde was prepared from 5-iodosalicylaldehyde in six steps in 18% overall yield, and also from 5-iodosalicylic acid in seven steps in 45% overall yield. The reaction of 5-*ortho*-carboranylsalicylaldehyde with Fischer's base gave a spiropyran in 63% yield.

**Keywords:** Coumarin, indolinospirobenzopyran, *ortho*-carborane, salicylaldehyde

Salicylaldehydes (2-hydroxybenzaldehydes) are key substrates for the synthesis of benzofurans, salen ligands, coumarins, and indolinospirobenzopyrans, which are very important skeletons in organic chemistry, medicinal chemistry, and/or material chemistry. The benzofurans are highly valuable molecular motifs often found in various natural products and in molecules, showing a variety of pharmacological properties.[1] The salen ligands have received considerable attention in various asymmetric organic reactions[2] since Zhang et al.[3] and Irie et al.[4] reported significant success in asymmetric epoxidation of unfunctionalized olefins. Coumarins are found widely in nature[5] and have numerous applications in perfumery,[5] as dyes in laser technology,[6a] and as fluorescent indicators.[6b] Certain coumarins show inhibitory activity against several enzymes such as acetylcholinesterase, aromatase, and squalene cyclase.[7]

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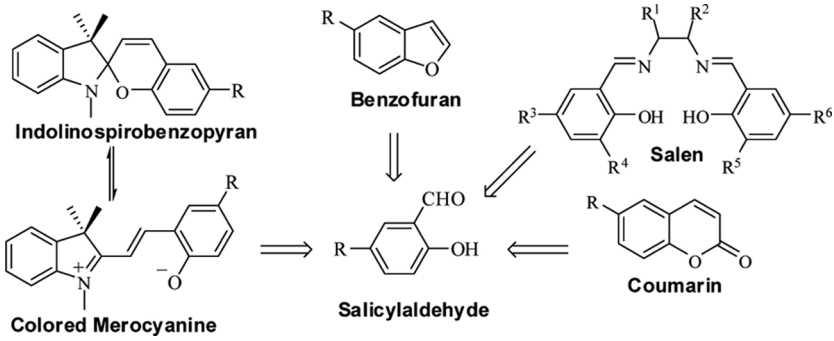


*Scheme 1.*

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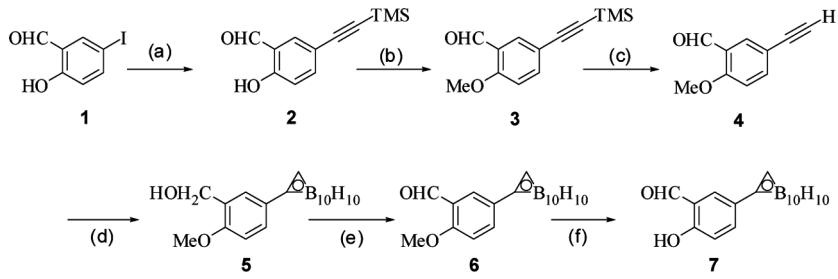
They also show biological activities such as anti-HIV, antifungal, anticlotting, and anticancer activity.[8] Photochromic indolinospirobenzopyran dyes have received considerable attention because of their potential application in many new technologies associated with equilibrium between colorless spiropyran form and colored merocyanine form (Scheme 1), including the area of rewritable optical memory and optical switching, nonlinear optics, and real-time holography.[9–11] Because the chemical, physical, and biological properties of these four important compounds are highly dependent on the substituent, it is important to develop the structural-change methods of the parent compounds of benzofurans, salens, coumarins, and indolinospirobenzopyrans.

The *ortho*-carborane ring system is highly lipophilic (i.e., the hydrophobic parameter for *ortho*-carborane is $+4.20$)[12] with an extraordinary chemical and thermal stability. *ortho*-Carborane exerts stronger electron-withdrawing ($-$I) effects (similar to that of cyano group).[13] The size of *ortho*-carborane was only slightly larger than the size occupied by a phenyl ring, rotating about its C1–C4 axis.[14] The reasons to introduce an *ortho*-carborane as a substituent in salicylaldehyde are related to its properties, such as the electronic effect, steric effect, and lipophilicity of *o*-carborane ring, which might change the character of existing benzofurans, salens, indolinospirobenzopyrans, and coumarins. Here, we report the synthesis of 5-*ortho*-carboranylsalicylaldehyde from 5-iodosalicylaldehyde and 5-iodosalicylic acid and its application as a starting material for the synthesis of an indolinospirobenzopyran.

The first approach to synthesis of target molecule **5** from 5-iodosalicylaldehye is as follows (Scheme 2): Acetylenylsalicylaldehyde **2** was synthesized by the reaction of 5-iodosalicylaldehyde **1** with trimethylsilylacetylene under Sonogashira cross-coupling condition in 80% yield. The salicylaldehyde **2** was protected by methylation in refluxing methylene




***Scheme 2.*** (a) TMSA, $PdCl_2$, $PPh_3$, CuI, $Et_3N$ in $CH_3CN$ at reflux, overnight, 80%; (b) MeI, $K_2CO_3$ in acetone at reflux, 0.5 h, 94%; (c) $K_2CO_3$ in methanol at rt, 0.5 h, quantitative; (d) $B_{10}H_{14}$ in $CH_3CN$/toluene at reflux, 1 h, 34.1%; (e) PCC in $CH_2Cl_2$ at rt, 3 h, 92%; (f) $BBr_3$ in DCM at 0°C, 5 h, 75%.

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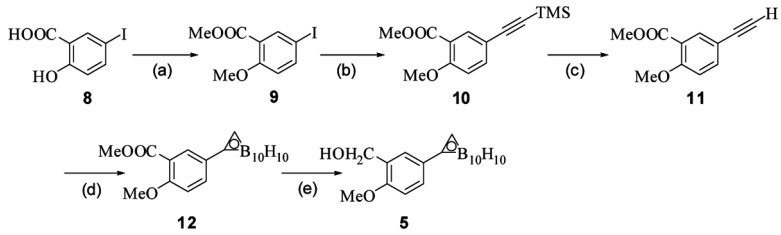
chloride using methyl iodide[15] followed by desilylation[16] using potassium carbonate at rt to give acetylene **4** in 94% and quantitative yields for each step. The reason to protect the hydroxyl group is that the *ortho*-carborane ring system was not formed without protection of acidic hydroxyl group of 2-hydroxybenzaldehyde under the reported reaction condition.[17] The reaction of benzaldehyde **4** with decaborane in a refluxing solution of acetonitrile and toluene gave *ortho*-carboranylbenzylalcohol **5** in 34.1% yield. The alcohol functional group was reoxidized to aldehyde using pyridinium chlorochromate (PCC) in methylene chloride[18] at rt to give aldehyde **6** in 92% yield, which was demethylated using $BBr_3$ in tetrahydrofuran (THF)[19] to give the final 5-*ortho*-carboranylsalicylaldehyde in 75% yields.

The overall yield of the synthesis of 5-*ortho*-carboranylsalicylaldehyde from 5-iodosalicylaldehyde was poor (18%) due to the conversion step of an acetylene **4** to *ortho*-carborane **5**. Therefore, the alternative second approach (Scheme 3) was attempted, starting from the commercially available 5-iodosalicylic acid, for the preparation of benzyl alcohol **5**. 5-Iodosalicylic acid **8** was protected with a methyl group using methyl iodide and potassium carbonate in acetonitrile followed by Sonogashira coupling with trimethylsilylacetylene to give the coupling product **10** in 91% and quantitative yields, respectively. Compound **10** was desilylated using potassium carbonate in methanol to give terminal acetylene **11** in 89% yield, which in turn coupled with decaborane to afford *ortho*-carboranyl compound **12** in 82% yield. The reduction of ester **12** using lithium aluminum hydride gave benzyl alcohol **5** in 99% yield. The overall yield of this second approach is 45%, which is better than that of the first approach.

5-*ortho*-Carboranylsalicylaldehyde might be an intermediate for the synthesis of benzofurans, indolinospirobenzopyrans, coumarins, and salens. As an example, *ortho*-carboranylspiropyran **13**, which can not




***Scheme 3.*** (a) MeI, $K_2CO_3$, acetone, 6 h, 91%; (b) TMSA, $PdCl_2$, $PPh_3$, CuI, $Et_3N$, 2 h, quantitative; (c) $K_2CO_3$, MeOH, 0.5 h, 89%; (d) $B_{10}H_{14}$, acetonitrile/toluene, 4 h, 82%; (e) $LiAlH_4$, DCM, 30 min, 99%.

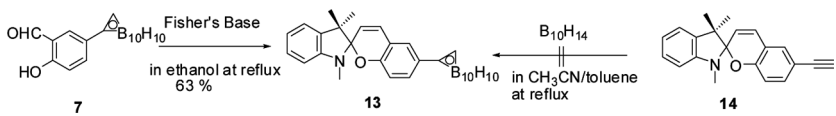
be prepared by the direct reaction of acetylenylspiropyran **14** with decaborane under reflux condition, was prepared by the reaction of 5-*ortho*-carboranylsalicylaldehyde with Fischer's base in ethanol under reflux condition in 63% yield (Scheme 4). The reaction of acetylenylspiropyran **14** with decaborane in a solution of acetonitrile and toluene at reflux gave a black precipitate, which was not identifiable.

In conclusion, 5-*ortho*-carboranylsalicylaldehyde, which might be good substrate of benzofurans, indolinospirobenzopyrans, salen ligands, and coumarins, was prepared from 5-iodosalicylaldehyde in six steps in 18% overall yield and also from 5-iodosalicylic acid in seven steps in 45% overall yield. The 5-*ortho*-caboranylsalicylaldehyde reacted with Fischer's base in ethanol at reflux to afford an *ortho*-carboranylindolinospirobenzopyran in 63% yield.

## EXPERIMENTAL

### 5-(Trimethylsilylacetylenyl)salicylaldehyde (2)

A solution of 5-iodosalicylaldehyde **1** (10.0 g, 40.3 mmol), trimethylsilylacetylene (8.55 mL, 60.5 mmol, 1.5 equiv.), $PdCl_2$ (358 mg, 2.02 mmol, 5 mol%), $Ph_3P$ (1.06 g, 4.03 mmol, 10 mol%), CuI (0.19 g, 1.01 mmol, 2.5 mol%), and triethylamine (39.4 mL, 282 mmol, 7 equiv.) was heated at reflux under an argon atmosphere. After 3 h of reflux, the reaction




***Scheme 4.*** Synthesis of *ortho*-carboranylindolinospirobenzopyran.

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mixture was filtered through a celite pad. The filtrate was concentrated under reduced pressure and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:4) to afford 5-(trimethylsilylacetylenyl)salicylaldehyde **2** (7.04 g, 32.3 mmol, 80.0%) as a yellow-brown solid: mp 94–96°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 11.10 (s, 1H), 9.86 (s, 1H), 7.71 (s, 1H), 7.61 (d, $J = 8.8$ Hz, 1H), 6.94 (d, $J = 8.8$ Hz, 1H), 0.23 (s, 9H). Anal. calcd. for $C_{12}H_{14}O_2Si$: C, 66.02; H, 6.46. Found: C, 65.64; H, 6.43.

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### 2-Methoxy-5-(trimethylsilylacetylenyl)benzaldehyde (3)

Methyl iodide (0.69 ml, 11 mmol, 2 equiv.) was added to a heterogeneous solution of a salicylaldehyde **2** (1.2 g, 5.5 mmol) and potassium carbonate (3.8 g, 27.5 mmol) in acetonitrile (20 ml). The resulting solution was stirred at reflux under argon atmosphere. After 30 min of reflux, the mixture was cooled down and filtered through filter paper to remove salts. The filtrate was concentrated under reduced pressure and purified by column chromatography on silica gel (ethyl acetate and hexane = 1:20) to give 2-methoxybenzaldehyde **3** (1.20 g, 5.18 mmol, 94.2%) as an ivory solid: mp 111–112°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 10.40 (s, 1H), 7.93 (s, 1H), 7.62 (d, $J = 8.8$ Hz, 1H), 6.92 (d, $J = 8.8$ Hz, 1H), 3.94 (s, 3H), 0.23 (s, 9H). Anal. calcd. for $C_{13}H_{16}O_2Si$: C, 67.20; H, 6.94. Found: C, 65.00; H, 7.04.

### 5-Acetylenyl-2-methoxybenzaldehyde (4)

A solution of a 2-methoxybenzaldehyde **3** (1.0 g, 4.3 mmol) and $K_2CO_3$ (0.9 g, 6.5 mmol, 1.5 equiv.) in methanol (20 mL) was stirred for 30 min at rt. After the concentration of the reaction mixture under reduced pressure, ethyl acetate (20 ml) was added and filtered through filter paper, and the filtrate was concentrated and chromatographed on silica gel (ethylacetate–hexane = 1:4) to give aldehyde **4** (689 mg, 4.30 mmol, quantitative) as a yellow-colored solid: mp 82–83°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 10.42 (s, 1H), 7.95 (s, 1H), 7.66 (d, $J = 8.8$ Hz, 1H), 6.96 ($J = 8.8$ Hz, 1H), 3.96 (s, 3H), 3.03 (s, 1H).

### 5-(1,2-Dicarba-*closo*-dodecaboranyl)-2-methoxybenzylalcohol (5)

A solution of decaborane (1.8 g, 15.0 mmol, 1.2 equiv.) in dry acetonitrile (20 mL) was heated at reflux for 5 h under argon atmosphere. A solution

of 5-ethynyl-2-methoxybenzaldehyde **4** (2.0 g, 12.5 mmol) in benzene (60 mL) was added dropwise to this solution. The mixture was heated at reflux for 80 h. The reaction mixture was concentrated and chromatographed on silica gel (methanol and methylene chloride = 2:98) to give a *ortho*-carboranyl benzylalcohol **5** (2.98 g, 10.6 mmol, 34.1%) as a white solid: mp 121–122°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 7.41–7.44 (m, 2H), 6.80 (d, $J = 9.6$ Hz, 1H), 4.66 (s, 2H), 3.91 (br s, 1H), 3.86 (s, 3H). Anal. calcd. for $C_{10}H_{20}B_{10}O_2$: C, 42.84; H, 7.19. Found: C, 42.83; H, 7.30.

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### 5-(1,2-Dicarba-*closo*-dodecaboranyl)-2-methoxybenzaldehyde (6)

Pyridium chlorochromate (2.3 g, 10.7 mmol, 3 equiv.) was added to a solution of benzylalchol **5** (1.0 g, 3.57 mmol) in dichloromethane (30 mL) at room temperature. After the heterogeneous reaction solution was stirred at room temperature for 3 h, it was diluted with dichloromethane (50 ml) and filtered through a celite pad. The filtrate was concentrated and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:4) to give a benzaldehyde **6** (912 mg, 3.28 mmol, 91.9%) as a yellow solid: mp 108–109°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 10.41 (s, 1H), 7.87 (s, 1H), 7.73 (d, $J = 8.8$ Hz, 1H), 6.97 (d, $J = 8.8$ Hz, 1H), 3.96 (s, 3H), 3.87 (br s, 1H). Anal. calcd. for $C_{10}H_{18}B_{10}O_2$: C, 43.15; H, 6.52. Found: C, 43.22; H, 6.50.

### 5-(1,2-Dicarba-*closo*-dodecaboranyl)-2-hydroxybenzaldehyde (7)

A solution of boron tribromide (5.8 mL, 5.8 mmol, 2 equiv.) in dichloromethane was added dropwise to a solution of compound **6** (800 mg, 2.87 mmol) in dichloromethane (50 mL) at −78°C (in a dry ice/2-propanol bath) under argon. The cold bath was removed, and the reaction mixture was stirred for 4 h under an argon atmosphere, poured into ice water, stirred for 30 min, saturated with NaCl, and extracted with dichloromethane. The extract was dried with anhydrous magnesium bromide, concentrated, and chromatographed on silica gel (ethyl acetate and hexane = 1:10) to give the product **7** (570 mg, 2.16 mmol, 75%) as a white solid: mp 165–166°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 11.12 (s, 1H), 9.90 (s, 1H), 7.73 (s, 1H), 7.65 (d, $J = 8.8$ Hz, 1H), 6.97 (d, $J = 8.8$ Hz, 1H), 3.89 (br s, 1H). Anal. calcd. for $C_9H_{16}B_{10}O_2$: C, 40.89; H, 6.10. Found: C, 38.92; H, 5.78.

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**Methyl 5-iodo-2-methoxybenzoate (9)**

A solution of 5-iodosalicylic acid **8** (4.0 g, 15.15 mmol), potassium carbonate (21.0 g, 152 mmol, 10 equiv.), and methyl iodide (9.4 ml, 152 mmol, 10 equiv.) in acetonitrile (50 ml) was heated at reflux under argon. After 6 h of reflux, the mixture was cooled down, filtered through filter paper, and concentrated under reduced pressure. The concentrate was chromatographed on silica gel using a solution of ethyl acetate and hexane (1:6) to give ester **9** (4.0267 g, 13.79 mmol, 91.0%) as a brown solid: mp 47–48°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 8.07 (s, 1H), 7.73 (d, $J = 8.4$ Hz, 1H), 6.76 (d, $J = 8.4$ Hz, 1H), 3.88 (s, 6H). Anal. calcd. for $C_9H_9IO_3$: C, 37.01; H, 3.11. Found: C, 37.04; H, 3.12.

**Methyl 5-(trimethylsilylacetylenyl)-2-(methoxy)benzoate (10)**

A solution of ester **9** (4.00 g, 13.7 mmol), trimethylsilylacetylene (2.9 ml, 21 mmol, 1.5 equiv.), palladium(II) chloride (121 mg, 0.685 mmol, 0.05 equiv.), triphenylphosphine (360 mg, 1.37 mmol, 0.1 equiv.), copper iodide (65.2 mg, 0.025 equiv.), and triethylamine (13.4 mL, 95.9 mmol, 7 equiv.) in acetonitrile (100 mL) was heated at reflux. After 2 h of reflux, it was filtered through celite pad, and the filtrate was concentrated and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:10) to afford a coupling product **10** (3.59 g, 13.7 mmol, quantitative) as sticky brown oil. $^1$H NMR ($CDCl_3$, 300 MHz): δ 7.92 (s, 1H), 7.56 (d, $J = 8.4$ Hz, 1H), 6.90 (d, $J = 8.4$ Hz, 1H), 3.91 (s, 3H), 3.88 (s, 3H), 0.24 (s, 9H).

**Methyl 5-(acetylenyl)-2-(methoxy)benzoate (11)**

A solution of compound **10** (1.0 g, 3.8 mmol) and $K_2CO_3$ (790 mg, 5.7 mmol, 1.5 equiv.) in methanol (10 mL) was stirred at room temperature for 30 min. After concentration, ethyl acetate (50 ml) and water (20 ml) were added. The ethyl acetate layer was separated, washed with water (20 ml × 2) and brine solution (20 ml), dried on anhydrous magnesium sulfate, and filtered. The filtrate was concentrated and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:5) to give an acetylenylbenzoate **11** (646 mg, 3.39 mmol, 89.1%) as a yellow solid: mp 61–62°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 7.94 (s, 1H), 7.59 (d, $J = 8.7$ Hz, 1H), 6.93 (d, $J = 8.7$ Hz, 1H), 3.92 (s, 3H), 3.89 (s, 3H), 3.02 (s, 1H). Anal. calcd. for $C_{11}H_{10}O_3$: C, 69.40; H, 5.30. Found: C, 69.19; H, 5.49.

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**Methyl 5-(1,2-dicarba-*closo*-dodecaboranyl)benzoate (12)**

Decaborane (1.93 g, 15.8 mmol, 1.5 equiv.) in dry acetonitrile (20 mL) was heated at reflux for 3 h under an argon atmosphere. A solution of compound **11** (2.00 g, 10.5 mmol) in toluene (60 mL) was added to the solution. After the resulting solution was refluxed for 4 h, it was concentrated and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:5) to give the product **12** (2.65 g, 8.6 mmol, 81.9%) as a white solid: mp 150–151°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 7.88 (s, 1H), 7.62 (d, $J = 8.7$ Hz, 1H), 6.92 (d, $J = 8.7$ Hz, 1H), 3.91–3.92 (m, 7H). Anal. calc. for $C_{11}H_{20}B_{10}O_3$: C, 42.84; H, 6.54. Found: C, 42.71; H, 6.76.

**5-(1,2-Dicarba-*closo*-dodecaboranyl)-2-methoxybenzylalcohol (5)**

Lithium aluminum hydride (16 mL, 16 mmol, 1.0 M in ether) was added dropwise to a solution of **12** (1.0 g, 3.2 mmol) in ether (4 ml) at 0°C with stirring. The mixture was stirred for 1 h at 0°C. After quenching with saturated aqueous ammonium chloride solution, the mixture was extracted with ether and dried over anhydrous magnesium sulfate. Evaporation of the solvents followed by purification using silica-gel column chromatography (ethyl acetate and hexane = 1:4) afforded **5** (886 mg, 3.16 mmol, 98.9%) as a white solid.

**6-(1,2-Dicarba-*closo*-dodecaboranyl)spiropyran (13)**

A solution of 2-methylene-1,3,3-trimethylindoline (655 mg, 3.8 mmol, 1 equiv.) in ethanol (10 mL) was added dropwise to a solution of 5-*ortho*-carboranylsalicylaldehyde **7** (1.0 g, 3.8 mmol) in ethanol (20 mL) under reflux. After the resulting solution was heated under reflux for 2 h, the reaction mixture was concentrated and chromatographed on silica gel using a solution of ethyl acetate and hexane (1:10) to give a spiropyran **13** (1.00 g, 2.38 mmol, 63%) as a violet solid: mp 201–202°C. $^1$H NMR ($CDCl_3$, 300 MHz): δ 7.16–7.21 (m, 3H), 7.07 (d, $J = 7.2$ Hz, 1H), 6.85 (t, $J = 7.5$ Hz, 1H), 6.81 (d, $J = 10.5$ Hz, 1H), 6.63 (d, $J = 8.4$ Hz, 1H), 6.53 (d, $J = 7.8$ Hz, 1H), 5.76 (d, $J = 10.2$ Hz, 1H), 3.85 (br s, 1H), 2.71 (s, 3H), 1.23 (s, 3H), 1.16 (s, 3H). Anal. calcd. for $C_{21}H_{29}B_{10}NO$: C, 60.11; H, 6.97; N, 3.34. Found: C, 59.71; H, 7.21; N, 3.09.

## ACKNOWLEDGMENT

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## REFERENCES

1. (a) Rao, M. L. N.; Awasthi, D. K.; Banerjee, D. Microwave-mediated solvent-free Rap–Stoermer reaction for efficient synthesis of benzofurans. *Tetrahedron Lett.* **2007**, *48*, 431, and references cited therein; (b) Duan, X.-F.; Zeng, J.; Zhang, Z.-B.; Zi, G.-F. A facile two-step synthesis of 2-aryl-benzofurans based on the selective cross-McMurry couplings. *J. Org. Chem.* **2007**, *72*, 10283.
2. (a) Jacobsen, E. N. In *Catalytic Asymmetric Synthesis*; I. Ojima (Ed.): VCH: New York, 1993; pp. 159–202; (b) Cozzi, P. G. Metal-salen Schiff base complexes in catalysis: Practical aspects. *Chem. Soc. Rev.* **2004**, *33*, 410; (c) Ballistreri, F. P.; Patti, A.; Pedotti, S.; Tomaselli, G. A.; Toscano, R. M. Synthesis of novel chiral "salen-type" ferrocenyl ligands. *Tetrahderon: Asymmetry* **2007**, *18*, 2377.
3. Zhang, W.; Loedach, J.; Wilson, S. R.; Jacobsen, E. N. Enantioselective epoxidation of unfunctionalized olefins catalyzed by salen manganese complexes. *J. Am. Chem. Soc.* **1990**, *112*, 2801.
4. Irie, R.; Noda, K.; Ito, Y.; Matsumoto, K. T. Catalytic asymmetric epoxidation of unfunctionalized olefins. *Tetrahedron Lett.* **1990**, *31*, 7345.
5. (a) Murray, R. D. H. The naturally occurring coumarins. *Prog. Chem. Org. Nat. Prod.* **2002**, *83*, 1–673, and references therein; (b) Clark, G. S. Vanillin. *Perfum. Flavor.* **1995**, *20*, 23.
6. Brun, M.-P.; Bischoff, L.; Garbay, C. A very short route to enantiomerically pure coumarin-bearing fluorescent amino acids. *Angew. Chem., Int. Ed.* **2004**, *43*, 3432.
7. (a) Rollinger, J. M.; Hornick, A.; Langer, T.; Stuppner, H.; Prast, H. Acetylcholinesterase inhibitory activity of scopolin and scopoletin discovered by virtual screening of natural products. *J. Med. Chem.* **2004**, *47*, 6248; (b) Chen, S.; Cho, M.; Karlsberg, K.; Zhou, D.; Yuan, Y.-C. Biochemical and biological characterization of a novel anti-aromatase coumarin derivative. *J. Biol. Chem.* **2004**, *279*, 48071; (c) Cravotto, G.; Balliano, G.; Robaldo, B.; Oliaro-Bosso, S.; Chimichi, S.; Boccalini, M. Farnesyloxycoumarins: A new class of squalene-hopene cyclase inhibitors. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 1931.
8. (a) Kaye, P. T.; Musa, M. A.; Nichinda, A. T.; Nocanda, X. W. Novel heterocyclic analogues of the HIV-1 protease inhibitor ritonavir. *Synth. Commun.* **2004**, *34*, 2575; (b) Sardari, S.; Nishibe, S.; Daneshtalab, M. Coumarins, the bioactive structures with antifungal property. *Stud. Nat. Prod. Chem.* **2000**, *23*, 335; (c) Yu, D.; Suzuki, M.; Xie, L.; Morris-Natschke, S. L.; Lee, K.-H. Recent progress in the development of coumarin derivatives as potent anti-HIV agents. *Med. Res. Rev.* **2003**, *23*, 322; (d) Lacy, A.;

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O'Kennedy, R. Studies on coumarins and coumarin-related compounds to determine their therapeutic role in the treatment of cancer. *Curr. Pharm. Des.* **2004**, *10*, 3797.
9. Tomasulo, M.; Kaanumal, S. L.; Sortino, S.; Raymo, F. M. Synthesis and properties of benzophenone–spiropyran and naphthalene–spiropyran conjugates. *J. Org. Chem.* **2007**, *72*, 595.
10. Zhu, L.; Zhu, M.-Q.; Hurst, J. K.; Li, A. D. Q. Light-controlled molecular switchs modulate nanocrystal fluorescence. *J. Am. Chem. Soc.* **2005**, *127*, 8968, and references cited therein.
11. (a) Tamai, N.; Miyasaka, H. Ultrafast dynamics of photochromic systems. *Chem. Rev.* **2000**, *100*, 1875–1890; (b) Minkin, V. I. Photo-, thermo-, solvato-, and electrochromic spiroheterocyclic compounds. *Chem. Rev.* **2004**, *104*, 2751–2776.
12. Fauchere, J. L.; Do, K. Q.; Jow, P. Y. C.; Hansch, C. Unusually strong lipophilicity of "fat" or "super" amino-acids, including a new reference value for glycine. *Experientia* **1980**, *36*, 1203.
13. Hawthorne, M. F.; Berry, T. E.; Wegner, P. A. The electronic properties of the 1,2- and 1,7-dicarbaclovododecaborane (12) groups bonded at carbon. *J. Am. Chem. Soc.* **1965**, *87*, 4746.
14. Leukart, O.; Caviezel, M.; Eberle, A.; Escher, E.; Tun-Kyi, A.; Schwyzer, R. L-*o*-Carboranylalanine, a boron analogue of phenylalanine. *Helv. Chim. Acta.* **1979**, *59*, 2184.
15. Mackenzie, A. R.; Moody, C. J.; Rees, C. W. Synthesis of the bacterial coenzyme methoxatin. *Tetrahedron* **1986**, *42*, 3259.
16. Corey, E. J.; Snider, B. B. Total synthesis of (±)-fumagillin. *J. Am. Chem. Soc.* **1972**, *94*, 2549.
17. Garrigues, E.; Souchard, J.-P.; Nepveu, F. Synthesis of new lipophilic *ortho*-dicarboranes. *Tetrahedron Lett.* **1998**, *39*, 4489.
18. Coey, E. J.; Suggs, J. W. Pyridinium chlorochromate: An efficient reagent for oxidation of primary and secondary alcohols to carbonyl compounds. *Tetrahedron Lett.* **1975**, 2647.
19. Vickery, E. H.; Pahler, L. F.; Eisenbraun, E. J. Selective O-demethylation of catechol ethers: Comparison of boron tribromide and iodotrimethylsilane. *J. Org. Chem.* **1979**, *44*, 4444.

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