Absolute Conformation and Substituent Effects on Chiroptical Properties of 9-(2-Halo-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracenes[1,2]

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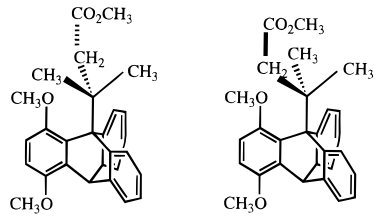
Abstract: Optically active and inactive rotational isomers of 9-(1,1-dimethyl-3-butenyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene were isolated. The absolute conformations of these optically active conformers were determined by correlating them with those of camphorsultam amides of 9-(2-carboxy-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracenes, the latter being determined by X-ray analysis. From the carboxylic acids, the title compounds, in which the halogen is a chloro, a bromo, or an iodo, were prepared. The CD spectra of the title compounds showed remote substituent effects on the Cotton effect at ca. 220 nm.

Stable conformational isomers which are optically active by virtue of chirality caused by restricted internal rotation have been isolated and their absolute conformations determined.[3,4] Theoretical predictions of the absolute conformations of such molecules will be helpful, when a compound is reluctant to afford suitable crystals for X-ray crystallography. However, prediction of absolute conformations by calculation is not necessarily reliable.

For example, we tried to assign absolute conformations of methyl 3-(1,4-dimethoxy-9-triptycyl)-3-methylbutanoate, of which enantiomers (***Msc*-1** and ***Psc*-1**) were isolated by chromatography on a chiral column.[5] The prediction was made by calculation with some reservations, but it was later proved that the absolute conformation was opposite to the prediction.[4] The ambiguity could be caused either by immaturity of the calculation level or by the conformations of the molecule: Although the rotation about the C(9) to the substiuent bond is frozen in compound **1**, the barrier being ca. 42 kcal/mol,[6] there are various conformations caused by rotation about the $CH_2—C_{CO}$ bond, which easily convert each other at room temperature. The presence of such conformers makes the calculation results ambiguous because the methoxycarbonyl group contributes to chiroptical properties differently in different conformations, of which populations are difficult to estimate.

If we could have a compound in which the internal rotation about the bond, e.g. the $CH_2—C_{CO}$ bond in compound **1**, is frozen also at room temperature, it would help in evaluating advantages and disadvantages of the theoretical method available today for calculating the chiroptical properties of a molecule. Although it is not possible to prepare such a compound today, it is possible to introduce a substituent which gives an identical rotamer, irrespective of the internal rotation, by virtue of symmetry.

Scheme 1



***Msc*-1** ***Psc*-1**

As the first example of such compounds, we selected the title compounds in which the halo-substituent in the 9-substituent is a chloro, a bromo, or an iodo. Though these compounds possess two methoxycarbonyl groups which allow internal rotation, the internal rotation of these moieties should be restricted to a large extent because of the steric requirement and other parts of the molecules are practically rigid. In addition, it can be assumed that average conformations of the methoxycarbonyl groups in these compounds are the same because of the same steric environments. In this paper, we report syntheses, isolation of rotational isomers, optical resolution of rotational isomers, and determination of absolute conformations of these compounds as well as their CD spectra.

A mixture of *ap* and ±*sc* rotamers of 9-(1,1-dimethyl-3-butenyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (**3**) was prepared by a Diels-Alder reaction of 9-(1,1-dimethyl-3-butenyl)anthracene (**2**) with dimethyl acetylenedicarboxylate (Scheme 2). This reaction afforded a mixture of rotamers in which the *ap* form predominated as was expected from the steric effects on the reaction.[7] The mixture could be made *sc*-isomer rich by heating it at 150° since there are two *sc* positions but only one *ap* orientation. The rotational isomers were separated by HPLC.

The ±*sc* rotamer was treated with alcoholic potassium hydroxide to hydrolyze the 12-methoxycarbonyl group. This

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(1) This paper is dedicated to Professor Nelson J. Leonard on the occasion of his 80th birthday.

(2) Part 5 of the series, Absolute Conformation and Chiroptical Properties. For Part 4, see Toyota, S.; Yasutomi, A.; Ōki, M. *Tetrahedron Lett.* **1995**, *36*, 6297−6300.

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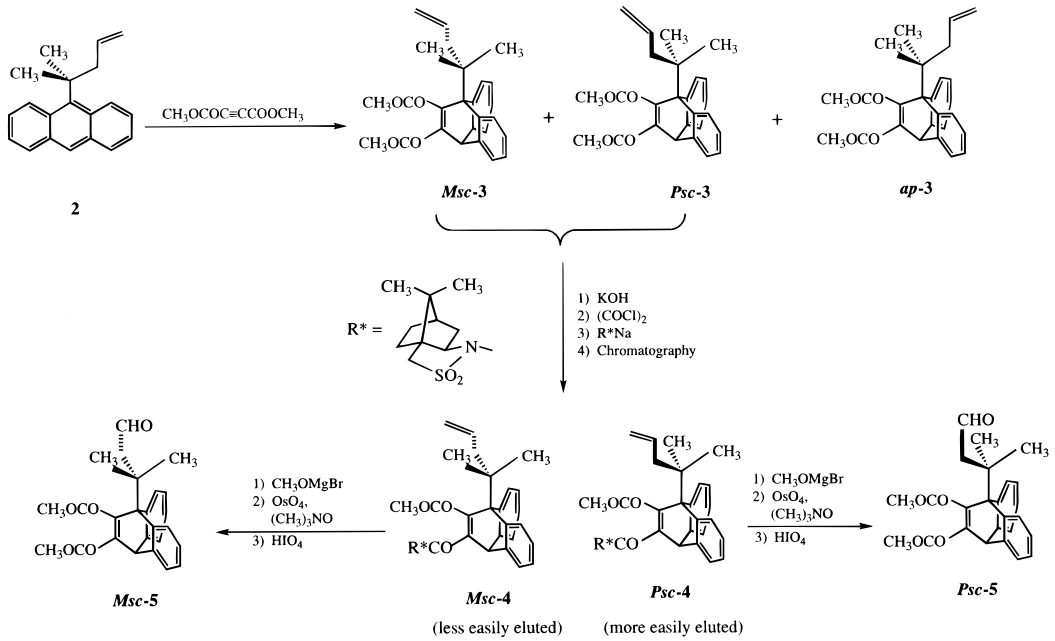
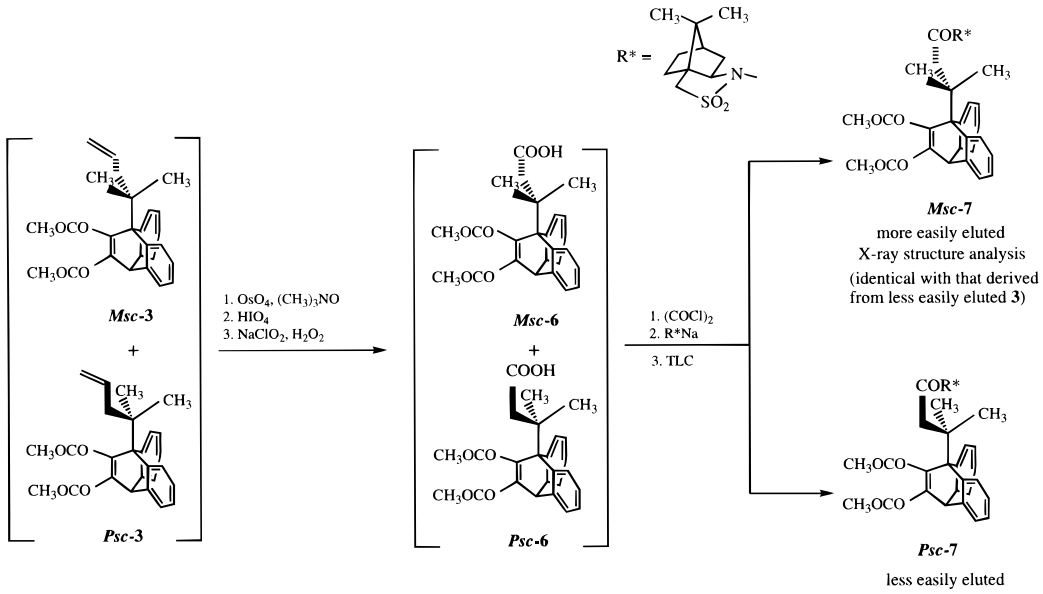
S0002-7863(96)01520-X CCC: $12.00

Scheme 2



Scheme 3



is possible because of the steric effects.[6] The carboxylic acid was converted to acid chloride by treatment with oxalyl dichloride and then to 4-{[9-(1,1-dimethyl-3-butenyl)-12-methoxycarbonyl-9,10-dihydro-9,10-ethenoanthracene]-11-carbonyl}-(1*S*,5*R*,7*R*)-10,10-dimethyl-3-thia-4-azatricyclo[3.2.1.0^{1,5}]decane 3,3-dioxide (**4**: hereafter referred to as 11-camphorsultamamide) by treating with sodium salt of (1*S*,5*R*,7*R*)-10,10-dimethyl-3-thia-4-azatricyclo[3.2.1.0^{1,5}]decane 3,3-dioxide (hereafter camphorsultam).[8] This chiral auxiliary is known to often give good results for resolution of carboxylic acids as well as good crystals for X-ray crystallography.[4,9] The diastereomers were separated by HPLC. Unfortunately however, neither of these diastereomers (**3**) gave suitable crystals for X-ray crystallography.

In order to determine absolute conformations of the series of compounds, we turned our attention to other possible pairs of diastereomers and found that 4-{3-[11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracen-9-yl]-3-methylbutanoyl}-(1*S*,5*R*,7*R*)-10,10-dimethyl-3-thia-4-azatricyclo[5.2.1.0^{1,5}]-decane 3,3-dioxide (**7**: hereafter 9-camphorsultamamide) gave suitable crystals for X-ray crystallography (Scheme 3). Namely, the racemic mixture of compound **3** was oxidized with osmium tetraoxide followed by periodic acid to afford a racemic mixture of the aldehyde (**5**), which was further oxidized to the corresponding carboxylic acid (**6**). The last oxidation posed a problem due to formation of complex mixtures by usual oxidation but this difficulty was overcome by using the method proposed by Dalcanale and Montanari.[10] The racemic acid (**6**)

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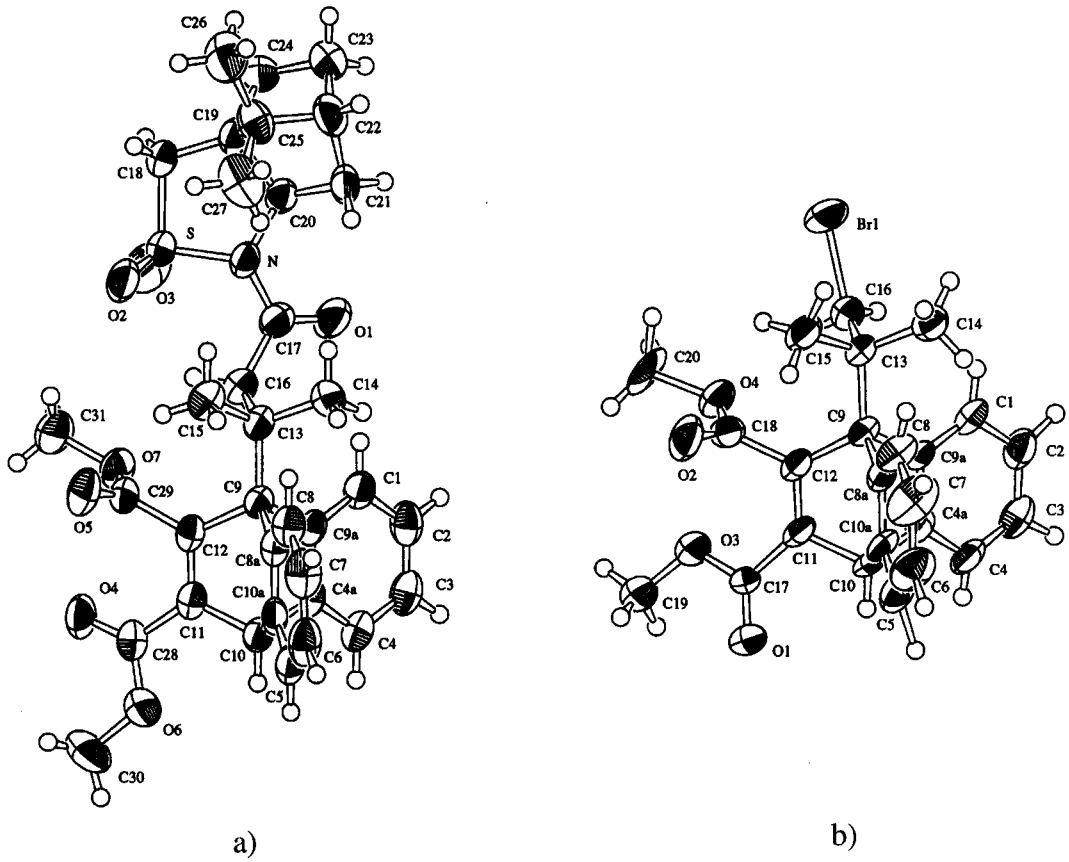

Figure 1. ORTEP drawings of (a) compound ***Msc*-7** and (b) compound ***Msc*-10**.

was converted to acid chloride and then treated with the sodium salt of camphorsultam. The resultant diastereomers (**7**) were separated by TLC and the more easily eluted isomer afforded crystals which were suitable for X-ray diffraction analysis.

An ORTEP drawing is shown in Figure 1. From the ORTEP drawing, the conformation about the bond connecting the C(9) of the ethenoanthracene skeleton and the 9-substituent is clearly *Msc*. The absolute conformation of this compound has thus become known. This compound has resisted hydrolysis of the camphorsultamamide moiety without affecting other parts of the molecule. Thus we decided to determine absolute conformations of optically active 11-camphorsultamamide (**4**) by converting it to the known conformation of 9-camphorsultamamide (**7**) (Schemes 2 and 3).

The conversion of 11-camphorsultamamide (**4**) to optically active **3** also posed various problems but we could overcome these problems with the use of methoxymagnesium bromide, this type of conversion being suggested originally with methoxide in methanol[11] and being used with benzyl alkoxide in ether.[12] The olefinic part in compound **3** was oxidized similarly as is described for the preparation of **6** and the optically active **6** was converted to the 9-camphorsultamamide (**7**). The 9-camphorsultamamide which was derived from the less easily eluted 11-camphorsultamamide was found to be identical with ***Msc*-7**. Thus the absolute conformations of these compounds are established.

Availability of quantities of these optically active compounds was limited, as prepared through HPLC of the 11-camphorsultamamide, but fortunately it was found that HPLC on a Chiralpack AD[13] column could separate the racemic aldehyde (**5**) into optically active ones rather easily. Thus enough quantity of ***Msc*-5** and ***Psc*-5** became available for chemical derivatization. Starting from the aldehyde, we prepared optically active acid (**6**), which was submitted to halodecarboxylation reactions with the use of Barton's 2(1*H*)-thioxo-1-pyridyl ester (**8**) (Scheme 4).[14] These reactions gave 2-halo derivatives (**9**, **10**, and **11**) in satisfactory yields. The halo compounds (**9**, **10**, and **11**) were also prepared in racemic forms and resolved by the same technique as for the aldehyde (**5**). The absolute conformations were assigned by synthesis of the same compound or comparison of retention times in HPLC of the compound from **5** of the known absolute conformation, when availability of the chiral compound is limited.

CD spectra of the halo compounds of *Psc* absolute conformation are shown in Figure 2. Apparently, the spectra are generally similar but vary in one major detail. The difference is that peaks and troughs centered at ca. 220 nm have a large amplitude when the substituent is a chlorine, whereas the amplitude decreases with increasing atomic weight. UV absorption spectra of these compounds show strong maxima at ca. 213 nm and small ones at ca. 279 nm. In addition, absorptions at ca. 202 and 225 nm were noticed due to the asymmetric nature of the absorption bands, the bromo compound (**10**) showing a distinct absorption maximum at 202 nm. Because the UV absorption maximum of 2,3-dimethyl-*cis*-2-butenedicarboxylic acid derivatives is known to be at 212.5 nm,[15] the Cotton effect at ca. 220 nm is tentatively ascribed to the $\pi-\pi^*$ transition of the bis(methoxycarbonyl)ethene group. Then it is concluded that the remote substituent affects the electronic transition of the enedicarboxylate moiety.

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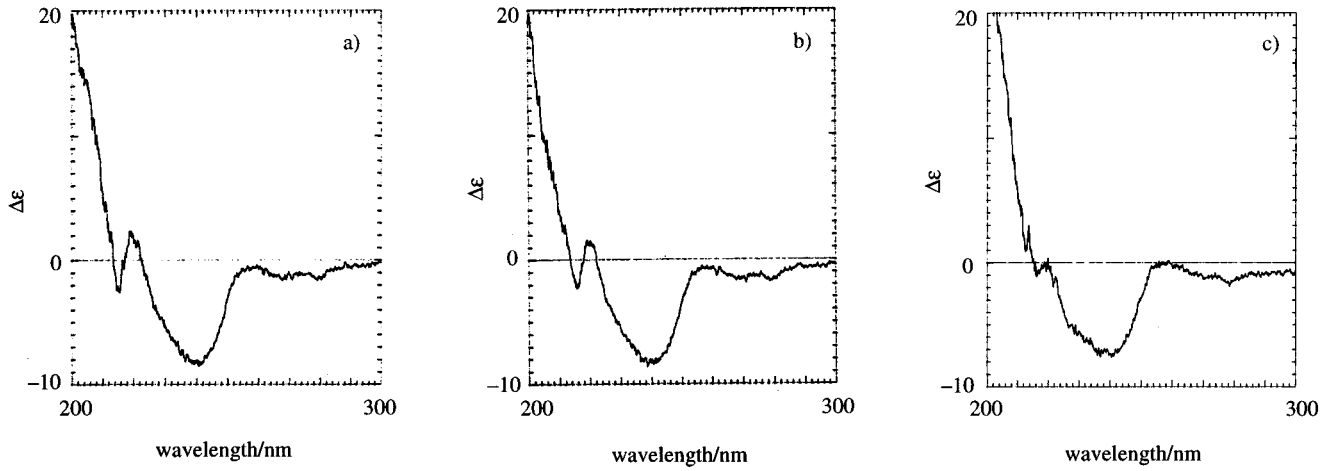
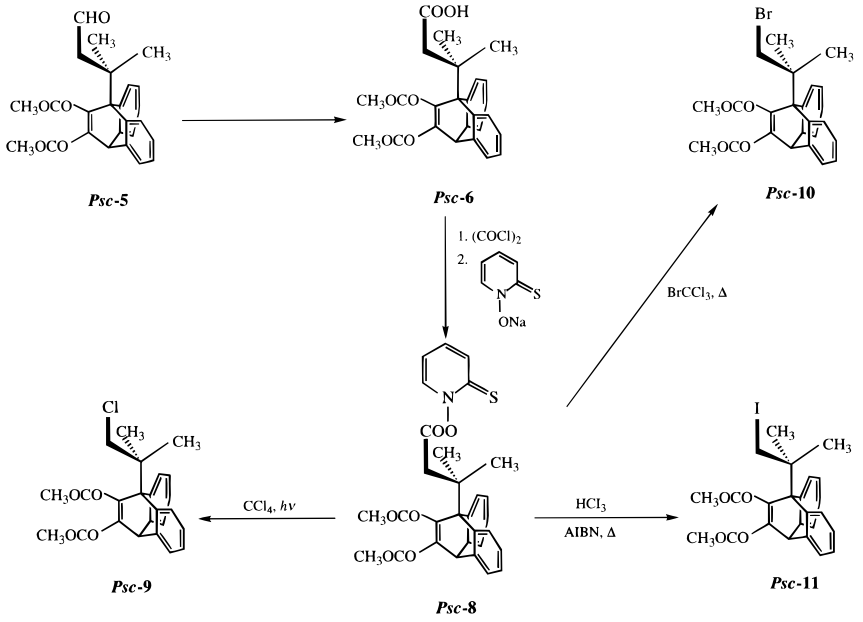


Figure 2. CD spectra of (a) compound ***Psc*-9**, (b) compound ***Psc*-10**, and (c) compound ***Psc*-11**.

Scheme 4



For confirmation of the structure of ***Msc*-10**, X-ray crystallography on this compound was carried out. An ORTEP drawing is given in Figure 1. Refinement of the crystallographic data assuming *Msc* stereochemistry led to an R_w value of 0.0491 while that with *Psc* gave R_w of 0.0582, confirming the assignment of the stereochemistry of this compound. As is seen in Figure 1, the C−Br bond is almost upright relative to the ethenoanthracence skeleton, the torsion angle Br(1)−C(16)−C(13)−C(9) being 169.7°. This stereochemical feature is caused by the steric effects of the methoxycarbonyl substituents and is seen for a similar compound [3] and triptycene derivatives of similar structure.[4,5,16] Because steric repulsion becomes severe when the bromine rotates about the C(16)−C(13) bond, we believe the conformation is essentially the same even in solution.

Experimental Section

^{1}H NMR spectra were measured on a Varian Gemini 300 spectrometer that operated at 300.1 MHz. UV spectra and CD spectra were recorded on a Hitachi U-2000 and on a JASCO J-600 spectrometers, respectively. Optical rotation was measured on a JASCO DIP-370 polarimeter with the use of a 3.5 mmϕ × 100 mm cell. Elemental analyses were carried out on a Perkin-Elmer 240C Analyzer. Melting points are not corrected.

9-(1,1-Dimethyl-3-butenyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (3). A solution of 11.7 g (45.0 mmol) of 9-(1,1-dimethyl-3-butenyl)anthracene[17] (**2**) in 60 mL of toluene was mixed with 12.0 g (98.0 mmol) of dimethyl acetylenedicarboxylate and was heated under reflux for 7 h. The solvent was evaporated and the residue was purified by chromatography on silica gel with 1:1 hexane−dichloromethane eluent. A rotamer mixture (*ap*:*sc* = 2:1) of the desired compound was obtained in 61% yield. This mixture (11.0 g) in 200 mL of *o*-dichlorobenzene was heated at 150 °C for 15 h for isomerization, when an *sc*-enriched mixture (*sc*:*ap* = 2:1) was obtained. The mixture was separated by HPLC (Develosil 60−5, 5:1 hexane−ether eluent, flow rate 25 mL/min), the retention times being 16−18 min and 18−21 min for *sc* and *ap* isomers, respectively.

***sc*-3** was purified by recrystallization from dichloromethane−hexane, mp 141−142 °C. Found: C, 77.37; H, 6.47%. Calcd for $C_{26}H_{26}O_4$: C, 77.59; H, 6.51%. ^{1}H NMR ($CDCl_3$) δ = 1.82 (3H, s), 1.88 (3H, s), 2.85 and 3.23 (2H, AB of ABX, J_{AB} = 14.5, J_{AX} = 6.3, and J_{BX} = 7.8 Hz), 3.72 (3H, s), 3.77 (3H, s), 5.20−5.24 (2H, m), 5.53 (1H, s), 6.05−6.18 (1H, m), 6.98−7.04 (4H, m), 7.35−7.39 (2H, m), 7.68−7.75 (2H, m).

***ap*-3** was recrystallized from dichloromethane−hexane, mp 151−152 °C. Found: C, 77.65; H, 6.55%. Calcd for $C_{26}H_{26}O_4$: C, 77.59;

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H, 6.51%. ^{1}H NMR ($CDCl_3$) δ = 1.76 (6H, s), 3.14 (2H, d, J = 7.5 Hz), 3.71 (3H, s), 3.76 (3H, s), 5.15−5.27 (2H, m), 5.53 (1H, s), 6.09−6.24 (1H, m), 6.97−7.04 (4H, m), 7.35−7.41 (2H, m), 7.73−7.80 (2H, m).

Resolution of *sc*-3. A solution of 790 mg (2.03 mmol) of ***sc*-3** in 40 mL of ethanol was heated under reflux for 15 min with 420 mg (7.49 mmol) of potassium hydroxide and then acidified with 1 N hydrochloric acid after removal of the solvent. Extraction with ether, drying, and evaporation of the solvent gave a white solid which was purified by recrystallization from ether−hexane. *sc-9-(1,1-Dimethyl-3-butenyl)-11-methoxycarbonyl-9,10-dihydro-9,10-ethenoanthracene-12-carboxylic acid*, mp 203.5−205.0 °C, was obtained in 85% yield. Found: C, 77.08; H, 6.35%. Calcd for $C_{25}H_{24}O_4$: C, 77.30; H, 6.23%. ^{1}H NMR ($CDCl_3$) δ = 1.81 (3H, s), 1.87 (3H, s), 2.82 and 3.23 (2H, AB of ABX, J_{AB} = 14.2, J_{AX} = 6.8, and J_{BX} = 8.2 Hz), 3.69 (3H, s), 5.14−5.28 (2H, m), 5.50 (1H, s), 6.01−6.16 (1H, m), 6.96−7.05 (4H, m), 7.30−7.41 (2H, m), 7.67−7.78 (2H, m). The proton signal due to the COOH group was not detected.

A solution of the carboxylic acid (2.57 g or 6.61 mmol) and 3.0 mL of oxalyl dichloride in 70 mL of benzene was stirred for 3 h at room temperature and the solvent and excess of oxalyl dichloride were removed in vacuo. A solution was made by taking up the acid chloride in 70 mL of benzene and was added to a solution of sodium salt of camphorsultam, which was prepared by stirring a mixture of 421 mg (10.5 mmol) of sodium hydride and 1.86 g (8.64 mmol) of camphorsultam[18] in 25 mL of benzene for 1 h at room temperature. The mixture was stirred for 2 h and decomposed with excess of 1 N hydrochloric acid. The organic layer was dried and evaporated. The residue was submitted to chromatography on silica gel with 3:1 hexane−ethyl acetate eluent to roughly separate the 11-camphorsultamamide from unreacted camphorsultam. The mixture was further washed with 2 N aqueous sodium hydroxide to remove camphorsultam and the product was separated by HPLC (1:1 hexane−ether eluent, flow rate 20 mL/min), when *Psc*- and *Msc-11-camphorsultamamides* were eluted with retention times of 15−18 min and 19−22 min, respectively. The yields were 44 and 46% for the *Psc* and *Msc* isomers, respectively.

Psc-11-Camphorsultamamide, recrystallized from dichloromethane−hexane, mp 234−236 °C, $[\alpha]_D^{25}$ −118.5° (*c* 2.39, $CHCl_3$). Found: C, 71.68; H, 6.78; N, 2.31%. Calcd for $C_{35}H_{39}NO_5S$: C, 71.77; H, 6.71; N, 2.39%. ^{1}H NMR ($CDCl_3$) δ = 0.92 (3H, s), 1.14 (3H, s), 1.63 (3H, s), 1.92 (3H, s), 0.84−1.91 (7H, m), 3.20−3.49 (4H, m), 3.65 (3H, s), 3.87−3.91 (1H, m), 5.15 (1H, s), 5.17−5.27 (2H, m), 6.01−6.15 (1H, m), 6.96−7.04 (4H, m), 7.30−7.33 (1H, m), 7.38−7.41 (1H, m), 7.67−7.70 (1H, m), 7.75−7.78 (1H, m).

Msc-11-camphorsultamamide, recrystallized from dichloromethane−hexane, mp 231.0−233.5 °C, $[\alpha]_D^{26}$ −122.6° (*c* 2.46, $CHCl_3$). Found: 71.87; H, 6.78; N, 2.35%. Calcd for $C_{35}H_{39}NO_5S$: C, 71.77; H, 6.71; N, 2.39%. ^{1}H NMR ($CDCl_3$) δ = 0.93 (3H, s), 1.15 (3H, s), 1.87 (3H, s), 2.00 (3H, s), 0.84−1.98 (7H, m), 2.38 (1H, dd, J = 11.5 and 6.0 Hz), 3.16 (1H, dd, J = 13.4 and 8.2 Hz), 3.31 and 3.37 (2H, ABq, J = 13.7 Hz), 3.66 (3H, s), 3.88 (1H, dd, J = 4.3 and 7.8 Hz), 5.15−5.24 (3H, m), 6.04−6.18 (1H, m), 6.98−7.03 (4H, m), 7.26−7.33 (1H, m), 7.40−7.43 (1H, m), 7.63−7.66 (1H, m), 7.75−7.78 (1H, m).

A Grignard reagent was prepared from 297 mg (12 mmol) of magnesium, 1.0 mL (11 mmol) of propyl bromide and 20.5 mL of THF and 470 μL (11.6 mmol) of methanol in 10 mL of THF was added to this solution. ***Msc*-4** (2.0 g or 3.4 mmol) in 100 mL of THF was added to the resulted mixture and the whole was stirred for 75 h at room temperature. The mixture was decomposed with saturated aqueous ammonium chloride and the supernatant liquid was decanted. The solid was washed with ether and the combined organic layers were dried over magnesium sulfate. After filtration, the solvents were removed in vacuo, the residue was purified by chromatography on silica gel (4:1 hexane−ethyl acetate eluent) and the analytical sample was obtained by recrystallization from ethanol. The pure sample (***Msc*-3**), mp 164−165 °C, $[\alpha]_D^{29}$ −5.0° (*c* 3.54, $CHCl_3$), was obtained in 79% yield. Found: C, 77.70; H, 6.62%. Calcd for $C_{26}H_{26}O_4$: C, 77.59; H, 6.51%. The ^{1}H NMR spectra of this compound was identical with those of racemic ***sc*-3**.

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***Psc*-3**, mp 163.5−165.0 °C, $[\alpha]_D^{28}$ +4.4° (*c* 3.67, $CHCl_3$), was made similarly in 82% yield. Found: C, 77.59; H, 6.67%. Calcd for $C_{26}H_{26}O_4$: C, 77.59; H, 6.51%. This compound showed an identical ^{1}H NMR spectrum with ***Msc*-3**.

9(1′)-*Psc*-9-(2-Formyl-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene.[19] The vinyl compound (1.20 g or 2.98 mmol) was dissolved in 4 mL of acetone and mixed with 95 mL of *tert*-butyl alcohol and 1 mL of water. Trimethylamine oxide dihydrate (733 mg or 6.60 mmol), 32 μL (0.40 mmol) of pyridine, and 49 mg (0.19 mmol) of osmium tetraoxide were added to the solution and the mixture was stirred at room temperature for 1.5 h, when aqueous sodium hydrogensulfite was added until no more color change was observed. Aqueous sodium chloride was added and the mixture extracted with ether. The extracts were washed with dilute hydrochloric acid followed by aqueous sodium hydroxide and dried over magnesium sulfate. After filtration, the filtrate was evaporated to afford 1.62 g of a corresponding diol diastereomeric mixture, which was used directly for the next reaction.

To a solution of the mixture in 50 mL of THF, was added a solution of 812 mg (3.56 mmol) of periodic acid dihydrate in 15 mL of water. The mixture was stirred for 2 h at room temperature and decomposed with aqueous sodium thiosulfate. The mixture was treated similarly as above and the product was purified by chromatography on silica gel (5:1 hexane−ethyl acetate eluent). The total yield from the olefin was 70%. The analytical sample of ***Psc*-5** was obtained by recrystallization from hexane, mp 77.0−83.5 °C, $[\alpha]_D^{25}$ −29.0 ° (*c* 1.24, $CHCl_3$). Found: C, 74.05; H, 6.23%. Calcd for $C_{25}H_{24}O_5$: C, 74.24; H, 5.98%. ^{1}H NMR ($CDCl_3$) δ = 2.03 (3H, s), 2.08 (3H, s), 3.52 and 3.64 (2H, AB of ABX, J_{AB} = 16.3, J_{AX} = 0, and J_{BX} = 3.3 Hz), 3.72 (3H, s), 3.78 (3H, s), 5.53 (1H, s), 7.00−7.06 (4H, m), 7.37−7.40 (2H, m), 7.65−7.70 (2H, m), 10.06 (1H, dd, J = 3.3 and 1.5 Hz).

Similarly, ***Msc*-5** was obtained in 73% yield and was recrystallized from hexane, mp 76.0−85.0 °C, $[\alpha]_D^{25}$ +27.1 ° (*c* 1.16, $CHCl_3$). Found: C, 74.33; H, 6.21%. Calcd for $C_{25}H_{24}O_5$: C, 74.24; H, 5.98%. It showed an identical ^{1}H NMR spectrum with that of the *Psc* isomer.

Resolution of *sc*-5 by HPLC. This was carried out with a Chiralpac AD column (1.0 cmϕ × 25 cm) with 1:1 2-propanol−hexane eluent, a flow rate of 2.0 mL/min, and a charged amount of 4 mg per batch. The retention times were 22 and 36 min for ***Psc*-5** and ***Msc*-5**, respectively.

9(1′)-*Psc*-9-(2-Carboxy-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (*Psc*-6). To a solution of 817 mg (2.02 mmol) of the aldehyde in 30 mL of acetonitrile was added 260 μL of 30% aqueous hydrogen peroxide and 3 mL of phosphate buffer (p*H* 4−5). To the solution was added with stirring a solution of 340 mg (2.65 mmol) of 80% sodium chlorite in 25 mL of water at room temperature and the mixture was further stirred for 3.5 h. A solution of sodium hydrogensulfite (ca. 1.3 g) in 20 mL of water was added and the solution was stirred for 10 min to decompose the chlorite. The mixture was then acidified with 1 N hydrochloric acid and extracted with ether. After drying the extract, the solvent was evaporated to afford almost pure carboxylic acid in 95% yield. $[\alpha]_D^{25}$ +1.1° (*c* 1.66, $CHCl_3$). ^{1}H NMR ($CDCl_3$) δ = 2.02 (3H, s), 2.10 (3H, s), 3.19 and 3.74 (2H, ABq, J = 14.6 Hz), 3.76 (3H, s), 3.78 (3H, s), 5.54 (1H, s), 7.00−7.08 (4H, m), 7.37−7.40 (2H, m), 7.72−7.81 (2H, m), 8.52 (1H, br s). This compound was characterized as the methyl ester, mp 128.0−129.5 °C, $[\alpha]_D^{23}$ +3.0° (*c* 1.61, $CHCl_3$). Found: C, 72.12; H, 6.15%. Calcd for $C_{26}H_{26}O_6$: C, 71.87; H, 6.03%. ^{1}H NMR ($CDCl_3$) δ = 1.98 (3H, s), 2.00 (3H, s), 3.20 and 3.55 (2H, ABq, J = 14.5 Hz), 3.74 (3H, s), 3.77 (3H, s), 3.80 (3H, s), 5.53 (1H, s), 6.97−7.09 (4H, m), 7.34−7.43 (2H, m), 7.69−7.75 (1H, m), 7.77−7.82 (1H, m).

***Msc*-6** was similarly obtained in 99% yield. $[\alpha]_D^{25}$ −1.3° (*c* 1.67, $CHCl_3$). It gave an identical ^{1}H NMR spectrum with the *Psc* isomer. This compound was characterized as the corresponding methyl ester which was recrystallized from hexane, mp 130.0−131.5 °C, $[\alpha]_D^{23}$ −3.0° (*c* 1.61, $CHCl_3$). Found: C, 72.06; H, 5.98%. Calcd for $C_{26}H_{26}O_6$: C, 71.87; H, 6.03%. A ^{1}H NMR spectrum of this compound was identical with that of the *Psc* isomer.

9-Camphorsultamamide (7). A solution of 77 mg (0.18 mmol) of ±*sc* carboxylic acid (**6**), which was prepared similarly as described

(19) For designation of absolute conformation, see ref 3.

for the syntheses of optically active forms from racemic ***sc*-3**, and 0.50 mL (5.7 mmol) of oxalyl dichloride in 15 mL of benzene was stirred for 2 h at room temperature and the volatile materials were evaporated in vacuo. The residue was taken up in 15 mL of benzene and was added to a stirred solution of sodium camphorsultam which was prepared by stirring a mixture of 60 mg (0.28 mmol) of camphorsultam and 23 mg (0.56 mmol) of sodium hydride in 15 mL of benzene for 1 h at room temperature. After 1 h stirring, the solution was acidified with 1 N hydrochloric acid and the product extracted with ether. The diastereomers thus obtained were separated by TLC on silica gel with 1:2 hexane−ether eluent. The R_f values for *Psc* and *Msc* isomers were 0.24 and 0.17, respectively. The yields were 36% each for the isomers.

***Psc*-7**: recrystallized from ethanol, mp 212.0−213.5 °C, $[\alpha]_D^{24}$ −48.5° (*c* 1.19, $CHCl_3$). Found: C, 67.77; H, 6.46; N, 2.50%. Calcd for $C_{35}H_{39}NO_7S$: C, 68.05; H, 6.36; N, 2.27%. ^{1}H NMR ($CDCl_3$) δ = 1.01 (3H, s), 1.31 (3H, s), 1.35−1.50 (2H, m), 1.93 (3H, br s), 2.00 (3H, s), 2.11 (3H, s), 2.17−2.21 (2H, m), 3.44 and 3.51 (2H, ABq, *J* = 13.8 Hz), 3.37 and 4.18 (2H, ABq, *J* = 16.4 Hz), 3.73 (3H, s), 3.75 (3H, s), 3.95−3.99 (1H, m), 5.52 (1H, s), 6.98−7.03 (4H, m), 7.35−7.38 (2H, m), 7.66−7.75 (2H, m).

***Msc*-7**: recrystallized from ethanol, mp 218.0−219.5 °C, $[\alpha]_D^{24}$ −49.7° (*c* 1.05, $CHCl_3$). Found: C, 68.15; H, 6.46; N, 2.00%. Calcd for $C_{35}H_{39}NO_7S$: C, 68.05; H, 6.36; N, 2.27%. ^{1}H NMR ($CDCl_3$) δ = 0.98 (3H, s), 1.20 (3H, s), 1.38−1.45 (2H, m), 1.90−1.96 (3H, m), 2.04 (3H, s), 2.06 (3H, s), 2.14 (2H, d, *J* = 6.0 Hz), 3.33 and 3.37 (2H, ABq, *J* = 13.8 Hz), 3.53 and 4.11 (2H, ABq, *J* = 17.3 Hz), 3.72 (3H, s), 3.75 (3H, s), 4.00 (1H, t, *J* = 6.1 Hz), 5.51 (1H, s), 6.98−7.08 (4H, m), 7.35−7.38 (2H, m), 7.68−7.71 (1H, m), 7.90 (1H, d, *J* = 7.4 Hz).

9(1′)-*sc*-9-(2-Chloro-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (*Psc*-9 and *Msc*-9). A solution of 165 mg (0.392 mmol) of the *sc*-carboxylic acid (***sc*-6**) in 5 mL of dichloromethane was stirred at room temperature with 180 μL (2.1 mmol) of oxalyl dichloride for 3 h. The volatile materials were evaporated in vacuo to leave the acid chloride. A mixture of 55 mg (0.43 mmol) of sodium salt of 2-mercaptopyridine 1-oxide with 5 mL of cabon tetrachloride was degassed by beating with ultrasound wave under an argon atmosphere and was heated under reflux. To the refluxing mixture, was added with irradiation with a 15 W fluorescent lamp, the acid chloride dissolved in 3 mL of carbon tetrachloride, which was also degassed, in 15 min. The mixture was further heated under reflux for 20 min and the solvent evaporated. The residue was purified by TLC with 4:1 hexane−ethyl acetate eluent. The yield was 126 mg (78%).

The racemic mixture of ***sc*-9** was resolved by HPLC with the Chiralpac AD column under the following conditions: ethanol eluent, flow rate 1.4 mL/min, charged amount 4 mg per batch. The retention times were 19 and 42 min for ***Psc*-9** and ***Msc*-9**, respectively. These compounds were further purified by recrystallization from ethanol.

***Psc*-9**: mp 144−145 °C, $[\alpha]_D^{27}$ −9.7° (*c* 1.78, $CHCl_3$). Found: C, 70.16; H, 5.66%. Calcd for $C_{24}H_{23}ClO_4$: C, 70.16; H, 5.64%. ^{1}H NMR ($CDCl_3$) δ = 1.86 (3H, s), 2.04 (3H, s), 3.74 (3H, s), 3.78 (3H, s), 4.53 and 4.61 (2H, ABq, *J* = 11.4 Hz), 5.53 (1H, s), 7.00−7.05 (4H, m), 7.37−7.40 (2H, m), 7.62−7.70 (2H, m).

***Msc*-9**: mp 143.5−144.5 °C, $[\alpha]_D^{28}$ +9.7° (c 1.83, $CHCl_3$). Found: C, 70.17; H, 5.65%. Calcd for $C_{24}H_{23}ClO_4$: C, 70.16; H, 5.64%. It gave an identical ^{1}H NMR spectrum with the *Psc*-isomer.

***Psc*-9** was also prepared starting from *Psc*-carboxylic acid similarly as above in 79% yield. This reaction gave a compound which showed an identical ^{1}H NMR spectrum with above compounds. The retention time of HPLC with an analytical Chriralpac AD (0.45 cmϕ × 25 cm column, ethanol eluent, 0.4 mL/min flow rate) was 13.0 min, whereas the racemic mixture showed two peaks at 13.2 and 32.5 min retention times, for *Psc* and *Msc* isomers, respectively, under the same conditions.

9(1′)-*Msc*-9-(2-Bromo-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (*Msc*-10). A solution of 201 mg (0.478 mmol) of the *Msc*-carboxylic acid in 18 mL of benzene was mixed with 95 mg (0.57 mmol) of silver acetate and the mixture was heated under reflux for 40 min. The solvent was evaporated in vacuo and the residue was suspended in 10 mL of carbon tetrachloride. To this suspension was added 2.9 mL of 0.20 M bromine solution in carbon tetrachloride and stirred for 30 min at room temperature. Silver bromide was removed by filtration and the solvent was evaporated. The residue was purified by TLC with 4:1 hexane−ethyl acetate eluent. It was obtained in 13% yield, mp 140.5−142.0 °C, $[\alpha]_D^{26}$ −0.3° (*c* 0.64, $CHCl_3$), after recrystallization from ethanol. Found: C, 63.27; H, 4.94%. Calcd for $C_{24}H_{23}BrO_4$: C, 63.31, H, 5.09%. ^{1}H NMR ($CDCl_3$) δ = 1.87 (3H, s), 2.07 (3H, s), 3.73 (3H, s), 3.78 (3H, s), 4.50 and 4.55 (2H, ABq, *J* = 10.8 Hz), 5.53 (1H, s), 7.00−7.06 (4H, m), 7.36−7.39 (2H, m), 7.64−7.67 (2H, m).

9(1′)-*sc*-9-(2-Bromo-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (*Psc*-10 and *Msc*-10). The acid chloride of ***sc*-6** (177 mg or 0.421 mmol) was similarly prepared as described in the preparation of ***sc*-9**. To a boiling mixture of 65 mg (0.51 mmol) of sodium salt of 2-mercaptopyridine 1-oxide, 6 mg of 4-(dimethylamino)pyridine, and 5 mL of bromotrichloromethane, which was degassed, was added a solution of the acid chloride in 3 mL of bromotrichloromethane. After the similar treatment as the preparation of ***sc*-9**, the racemic product was obtained in 109 mg (58%) yield after TLC with 4:1 hexane−ethyl acetate. The racemic mixture was resolved by HPLC on the Chiralpac AD column under the following conditions: ethanol eluent, 1.4 mL/min flow rate, a charge of 4 mg per batch. The retention times were 20 and 40 min for ***Psc*-10** and ***Msc*-10**, respectively. They were further purified by recrystallization from ethanol. The ***Msc*-10** isomer showed the identical retention time with the bromo compound prepared from *Msc*-carboxylic acid by a Hunsdiecker bromodecarboxylation (see above).

***Psc*-10**: mp 141.5−142.5 °C, $[\alpha]_D^{28}$ +0.3° (*c* 1.77, $CHCl_3$). Found: C, 63.54; H, 5.20%. Calcd for $C_{24}H_{23}BrO_4$: C, 63.31; H, 5.09%. It showed an identical ^{1}H NMR spectrum with ***Msc*-10**.

***Msc*-10**: mp 141.5−143.0 °C, $[\alpha]_D^{28}$ −0.8° (*c* 1.79, $CDCl_3$). This compound was identical with the compound, of which preparation is described above, in every respect.

9(1′)-*sc*-9-(2-Iodo-1,1-dimethylethyl)-11,12-bis(methoxycarbonyl)-9,10-dihydro-9,10-ethenoanthracene (*Psc*-11 and *Msc*-11). The acid chloride was prepared similarly from 128 mg (0.304 mmol) of ***sc*-6** and its solution in 5 mL of toluene added to a mixture of 50 mg (0.353 mmol) of sodium salt of 2-mercaptopyridine 1-oxide, 134 mg (0.340 mmol) of iodoform and 9.5 mg of azobisisobutyronitrile in 3 mL of toluene. The product was similarly treated and 114 mg (75%) of the desired compound obtained. The racemic mixture was resolved by HPLC with the Chiralpac AD column under the following conditions: ethanol eluent, flow rate 1.4 mL/min, a charge of 4 mg per batch. The retention times were 22 and 32 min for ***Psc*-11** and ***Msc*-11**, respectively. The prodcuts were further purified by recrystallization from ethanol.

***Psc*-11**: mp 154.0−155.5 °C, solidifies and remelts at 282.5−284.0 °C. $[\alpha]_D^{28}$ +13.4° (*c* 1.85, $CHCl_3$). Found: C, 57.41; H, 4.59%. Calcd for $C_{24}H_{23}IO_4$: C, 57.38; H, 4.61%. ^{1}H NMR ($CDCl_3$) δ = 1.86 (3H, s), 2.05 (3H, s), 3.74 (3, s), 3.78 (3H, s), 4.43 (2H, s), 5.54 (1H, s), 7.00−7.05 (4H, m), 7.36−7.40 92H, m), 7.59−7.63 (2H, m). ^{1}H NMR in C_6D_6 showed the following signals (δ): 2.01 (3H, s), 2.10 (3H, s), 3.26 (3H, s), 3.41 (3H, s), 4.64 and 5.03 (2H, ABq, *J* = 10.5 Hz), 5.73 (1H, s), 6.75−6.85 (4H, m), 7.21−7.26 (2H, m), 7.56 (2H, d, *J* = 7.3 Hz).

***Msc*-11**: mp 156−157 °C, solidifies and remelts at 283.0−284.5 °C. $[\alpha]_D^{28}$ −13.2° (*c* 1.78, $CHCl_3$). Found: C, 57.55; H, 4.62%. Calcd for $C_{24}H_{23}IO_4$: C, 57.38; H, 4.61%. It showed an identical ^{1}H NMR spectrum with ***Psc*-11**.

***Msc*-11** was also prepared from *Msc*-carboxylic acid as described above in 59% yield. This compound showed the retention time of 23.9 min on an analytical column of Chiralpac AD under the same conditions as described for ***Psc*-8**, whereas a racemic mixture showed those of 15.2 and 23.7 min, respectively for *Psc* and *Msc* isomers.

UV Absorpton Spectra. These were recorded with methanol solutions of 0.74−1.00 × 10^{-4} mol/L for long wavelength regions and 1.00 × 10^{-5} mol/L for short wavelength regions. ***sc*-9**, ***sc*-10**, and ***sc*-11** showed almost superimposable spectra with peaks at ca. 212 (log ϵ 4.65) and 279 nm (log ϵ 3.18), but their shapes showed delicate differences due to the presence of the peak which was observed in CD spectra in addition to the presence of another absorption peak at ca. 205 nm, the bromo compound showing an absorption maximum at 202 nm.

CD Spectra. These were also recorded on methanol solutions with concentrations of (0.74−1.00) × 10^{-3} mol/L. A cell of 0.2 mm was

used for the wavelength region of 200−300 nm. The spectra were recorded eight times and the integrated spectra are shown in Figure 2. The following peaks and troughs were recorded (wavelength and $\Delta\epsilon$ are given): ***Psc*-9**, 215.5 (−2.63), 219.4 (1.71), and 240.9 (−8.31); ***Psc*-10**, 215.0 (−2.35), 220.0 (1.41), 240.0 (−8.24); ***Psc*-11**, 216.0 (−1.04), 220.0 (−0.26), 241.0 (−7.55).

X-ray Crystallography. Crystals used for the X-ray diffraction were grown from THF and ethanol for ***Msc*-10** and ***Msc*-7**, respectively. ***Msc*-10** crystallized with a stoichiometric amount of THF in the lattice. X-ray data were obtained on a Rigaku AFC7R four circle diffractometer with Cu $K\alpha$ radiation ($\lambda = 1.54178$ Å) with a 2θ scan mode in the range of $2\theta < 120°$, the scan rate being 12° and 16°/min for ***Msc*-10** and ***Msc*-7**, respectively. The scan range was calculated by $A° + 0.30°\tan\theta$, where *A*'s are 1.63 and 0.94 for ***Msc*-10** and ***Msc*-7**, respectively. The weak reflections were scanned three times. The structures were solved by the direct method and refined by the full-matrix least-square method by using the TEXSAN program. Anisotropic and isotropic thermal parameters were employed for non-hydrogen and hydrogen atoms, respectively. Some hydrogen atoms were refined but most of them were included in fixed positions. An empirical absorption correction based on azimuthal scans of several reflections was applied which resulted in transmission factors ranging from 0.59 to 1.00 and 0.88 to 1.00, for ***Msc*-10** and ***Msc*-7** respectively. The data were corrected for Lorentz and polarization effects. A correction for secondary extinction was applied (coefficient = 5.3992e − 06 for ***Msc*-10** and 3.01271e − 06 for ***Msc*-7**). The function minimized was $\Sigma[w(|F_o| - |F_c|)^2]$ where $w = (\sigma_c^2|F_o|)^{-1}$. Additional crystal and analysis data are listed in Table 1.

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Table 1. Crystal and Structure Analysis Data of ***Msc*-7** and ***Msc*-10**

compound	***Msc*-7**[a]	*Msc*-10
formula	$C_{39}H_{47}NO_8S$	$C_{24}H_{23}BrO_4$
fw	689.86	455.35
crystal system	monoclinic	orthorhombic
crystal dimensions/mm^3	0.10 × 0.15 × 0.40	0.62 × 0.75 × 1.00
space group	$P2_1$	$P2_12_12_1$
lattice type	primitive	primitive
a/Å	10.537(2)	11.479(2)
b/Å	16.511(2)	17.6324(8)
c/Å	11.240(1)	10.166(1)
β/°	112.533(9)	90
V/Å^3	1806.3(8)	2057.6(4)
Z	2	4
D_c/g cm^{-3}	1.268	1.470
μ/cm^{-1}	12.31	29.56
no. of reflcns	2959	1786
no. of obsvns	2595[b]	1703[c]
R	0.046	0.051
R_w	0.053	0.049

[a] Contains THF in 1:1 stoichiometry as a solvent of crystallization. [b] $I > 0.50\sigma(I)$. [c] $I > 1.20\sigma(I)$.

Supporting Information Available: Tables of atomic coordinates including hydrogens, anisotropic thermal parameters, experimental details of the X-ray study, bond distances and angles, and torsion angles for ***Msc*-7** and ***Msc*-10**, crystal packing diagram of ***Msc*-7**•THF, and UV absorption spectra (99 pages). See any current masthead page for ordering and Internet access instructions.

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