Convenient Synthesis of Chiral Cyclophanes that Can Coordinate to Metals

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Received November 12, 1998

Abstract: Optically pure cyclophanes possessing a 1,3-dicarbonyl moiety were conveniently synthesized from alkanedioyl dichloride in four steps. The intramolecular [4+2]cycloaddition of bis(acylketene)s generated by thermal decomposition of bis(4,6-dioxo-1,3-dioxane) proceeded smoothly, giving cyclophane pyranones in high yields. The compounds possessing 7−10 bridging methylenes were resolved by imine formation with (*R*)-1-phenylethylamine, followed by basic hydrolysis. These cyclophanes are optically active versions of acetylacetone or salicylaldehyde and formed complexes with metals such as copper and europium. X-ray analysis of the chiral copper complex indicated the pentacoordinated structure of the copper metal with syn configuration of the two bridging chains.

Cyclophanes, some of which can be chiral, are an interesting group of compounds.[1] When the ansa chain is sufficiently short, cyclophanes exhibit planar chirality due to the restricted rotation of the aromatic ring. The chirality might show chemical and physical properties different from those of the tetrahedral or the axial chirality. For example, since an enantioface of the aromatic ring in the cyclophane is shielded by the ansa chain, it can provide an effective chiral environment for asymmetric catalysis. It should also be noted that cyclophanes are a chiral equivalent of aromatic compounds. Since materials very often possess aromatic rings in their structure, substitution of such group with cyclophane converts achiral compounds to chiral, which can be an interesting approach for chiral materials. Quite a limited number of reports, however, appeared on the studies of chiral cyclophanes.[2,3] It may be due to the lack of an efficient synthetic method for optically pure cyclophanes with suitable functionalities. The syntheses have been rather lengthy, and therefore, introduction of functionalized groups was not facile. Described here is a convenient method for synthesizing cyclophanes **1**, which have a pyranone ring as the aromatic moiety (Figure 1). Optically pure **1** can be prepared from commercially available diacid dichlorides in a few steps using the intramolecular [4+2]cycloaddition of bis(acylketene)s[4−6] as the key step. These cyclophanes possessing a 1,3-dicarbonyl moiety are a chiral equivalent of acetylacetone or salicylaldehyde and are capable of coordinating to metals.

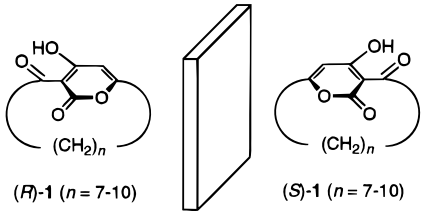

Figure 1. Chiral cyclophanes.

Bis(4,6-dioxo-1,3-dioxane)s **4** ($n = 6-12$, 16) were synthesized from the corresponding diacid dichlorides **2** ($n = 6-12$, 16) and Meldrum's acid **3** (Scheme 1 and Table 1) in the presence of pyridine at 0 °C to room temperature.[7] Then slow addition of **4** ($n = 7-12$, 16) to refluxing chlorobenzene under highly diluted conditions (1×10^{-4} M) gave (±)-**1** ($n = 7-12$, 16) generally in high yields. At temperatures higher than 130 °C, **4** ($n = 7-12$, 16) lost acetone and carbon dioxide generating bis(acylketene)s **5** ($n = 7-12$, 16),[6] which cyclized via [4+2]-cycloaddition. The high efficiency of the cyclophane formation may be ascribed to the very rapid reaction rate of the cycloaddition. The synthesis could be carried out on a 10 mmol scale, and the cyclophanes (±)-**1** ($n = 7-11$) were readily separated from oligomeric compounds by distillation. Higher homologues (±)-**1** ($n = 12$, 16) were isolated by chromatography on neutral silica gel, which contains a lower quantity of metal cations compared to the usual silica gel. Chromatography of **1** on the latter resulted in strong adsorption, and **1** was obtained as an orange material, probably due to chelation with metal cations

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10.1021/ja983907u CCC: $18.00
Published on Web 08/31/1999

Scheme 1

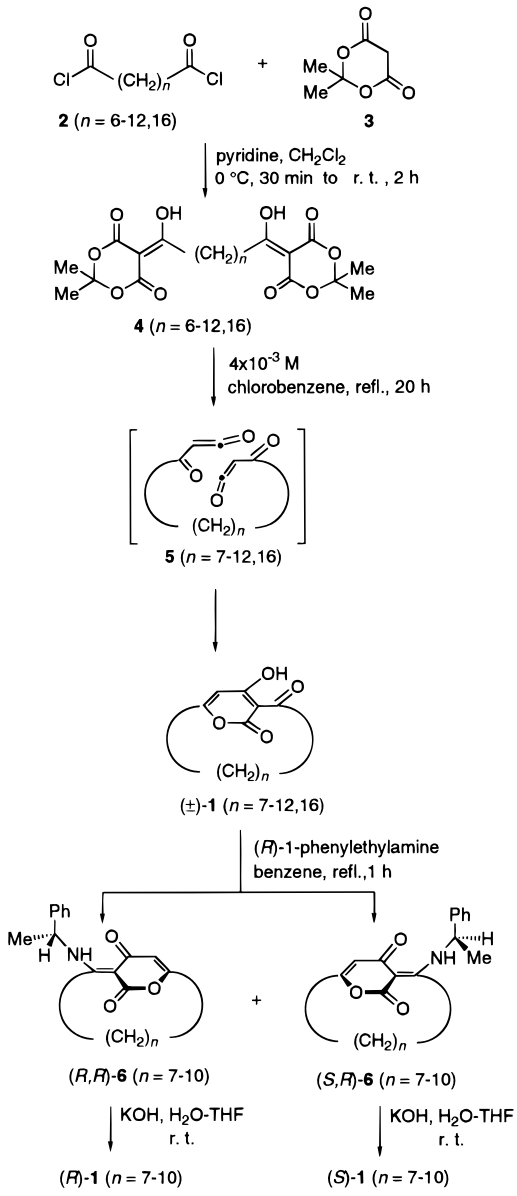


Table 1. Synthesis of Chiral Cyclophanes

	yield (%)					
n	**4**	(±)-**1**	**7a**/**7b**	(*R*,*R*)-**6**/(*S*,*R*)-**6**	(*R*)-**1**	(*S*)-**1**
6	76		18 (1:1)[a]			
7	88	27	28 (1:1)[a]	41:43	99	92
8	74	68	6 (1:1)[a]	41:36	100	100
9	74	88		41:40	85	97
10	75	90		50:48	87	99
11	71	87		57:43[b]		
12	70	82				
16	87	83				

[a] Isomer ratio is shown in parentheses. [b] The diastereomers were detected by ^{1}H NMR, although not isolable.

such as Fe^{3+}. The observations indicated the high affinity of **1** toward metals.

The yield of (±)-**1** (n = 7) decreased, and (±)-**1** (n = 6) could not be obtained under the present reaction conditions, which presumably was due to their strained nature. One of the bridging methylene protons of (±)-**1** (n = 7) appeared at δ 0.18 in ^{1}H NMR spectra, reflecting the close proximity of the proton to the pyranone ring. Dimeric products were obtained in the reactions of (±)-**4** (n = 6, 7, 8) as mixtures of two isomers **7a**

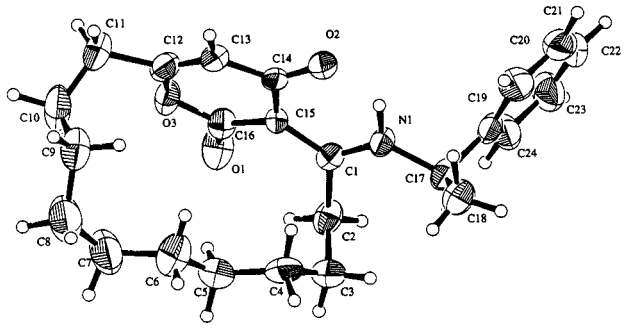
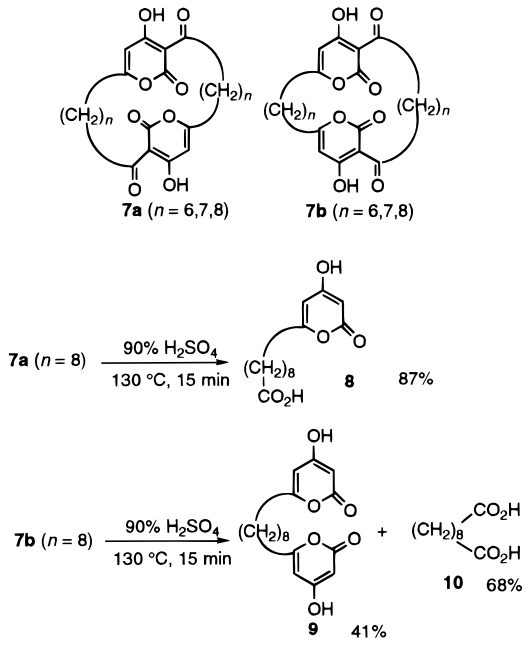


Figure 2. ORTEP drawing of (*R*,*R*)-**6** (n = 10) along with the atomic numbering scheme. Thermal ellipsoids are drawn at the 30% probability level.

Scheme 2



(*n* = 6, 7, 8) and **7b** (*n* = 6, 7, 8), while such dimers were not detected in the higher homologues (Table 1, Scheme 2). The structures of **7a** (*n* = 8) and **7b** (*n* = 8) were determined by chemical transformations: The treatment of **7a** (*n* = 8) with 90% sulfuric acid at 130 °C gave pyranonenonanoic acid **8**. Bis(pyranone) **9** and decanedioic acid **10** were obtained from **7b** (*n* = 8).

The cyclophanes (±)-**1** (*n* = 7−10) were resolved by treatment with (*R*)-1-phenylethylamine, followed by chromatographic separation to give diastereomeric imines (*S*,*R*)-**6** (*n* = 7−10) and (*R*,*R*)-**6** (*n* = 7−10) (Scheme 1 and Table 1). Although diastereomeric imines (*S*,*R*)-**6** (*n* = 11) and (*R*,*R*)-**6** (*n* = 11), which possessed a longer ansa chain, could be observed by ^{1}H NMR, they were not stable enough to be separated at room temperature. TLC of this mixture showed two spots only when the chromatography was conducted at −15 °C. A single imine compound was obtained from **6** (*n* = 12, 16). The relationship between the bridging chain length and the stability of the planar chirality is similar to that of known benzene and pyridine cyclophanes.[8] The configuration of (*R*,*R*)-**6** (*n* = 10) was determined by X-ray crystallographic analysis based on the (*R*)-configuration of the amine moiety (Figure 2 and Table 2).

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Table 2. Summary of Crystal Data, Data Collection, and Refinement Details

compound	(*R*,*R*)-**6** ($n = 10$)	(*R*,*R*)-**16** ($n = 8$)·acetone	(*R*,*R*)-**16** ($n = 9$)
formula	$C_{24}H_{31}O_3N$	$CuC_{31}H_{42}O_{10}$	$CuC_{30}H_{40}O_9$
formula weight	381.51	628.21	608.19
crystal size; mm	0.4 × 0.5 × 0.5	0.2 × 0.3 × 0.7	0.3 × 0.3 × 0.5
crystal system; space group	orthorhombic; $P2_12_12_1$	orthorhombic; $P2_12_12_1$	orthorhombic; $P2_12_12_1$
temp, K	293	150	150
a, Å	13.469 (3)	11.498 (1)	13.979 (2)
b, Å	14.966 (3)	28.745 (5)	15.684 (1)
c, Å	10.73 (1)	9.346 (1)	13.385 (1)
V, Å^3	2163 (2)	3088.8 (7)	2934.6 (5)
Z	4	4	4
D_{calcd}, g/cm^3	1.171	1.372	1.376
μ (MoKα), cm^{-1}	0.76	7.62	7.96
scan mode	2θ-ω	ω	2θ-ω
absorption correction	Ψ scans ($0.951 < T < 1.000$)	Ψ scans ($0.858 < T < 1.000$)	Ψ scans ($0.815 < T < 1.000$)
independent reflections	2438 (2θ max = 52°)	4288 (2θ max = 58°)	4735 (2θ max = 60°)
no. of obsd data [critical]	1252 [$Io > 2\sigma(Io)$]	3451 [$Io > 3\sigma(Io)$]	3897 [$Io > 3\sigma(Io)$]
no. of variables	253	380	522
$R = \Sigma\|\|F_o\| - \|F_c\|\|/\Sigma\|F_o\|$	0.069	0.051	0.034
$Rw = [\Sigma w(\|F_o\| - \|F_c\|)^2/\Sigma wF_o^2]^{1/2}$	0.059	0.053	0.034
($\Delta\rho$ max), eÅ^3	0.19	0.42	0.30
goodess of fit	2.03	2.49	1.89

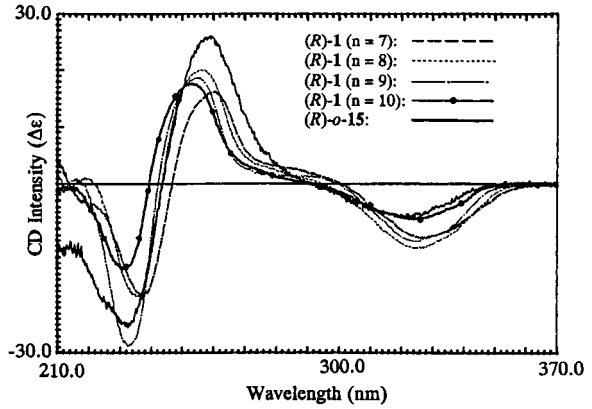


Figure 3. CD spectra of (*R*)-**1** ($n = 7, 8, 9, 10$) and (*R*)-*o*-**15** at the concentration of 0.082, 0.072, 0.076, 0.061, and 0.050 mM, respectively. The spectra of (*R*)-**1** ($n = 7, 8, 9, 10$) were obtained in hexane and (*R*)-*o*-**15** in actonitrile.

The amine moiety of (*S*,*R*)-**6** ($n = 8-10$) and (*R*,*R*)-**6** ($n = 8-10$) was removed by alkali treatment at room temperature for 20 h to give (*S*)-**1** ($n = 8-10$) and (*R*)-**1** ($n = 8-10$), respectively, without racemization (Scheme 1 and Table 1). In the cases of (*S*,*R*)-**6** ($n = 7$) and (*R*,*R*)-**6** ($n = 7$), however, partial racemization took place under these conditions, which may be caused by the hydrolysis of the lactone moiety. The racemization could be suppressed when the reaction was stopped after 2 h. The absolute configurations of (*R*)-**1** ($n = 7-9$) were determined by comparing their CD spectra with that of (*R*)-**1** ($n = 10$), which was derived from (*R*,*R*)-**6** ($n = 10$) (Figure 3). The CD spectra were very similar independent of the ansa chain length. The chirality of these cyclophanes was thermally stable, and no racemization took place in (*R*)-**1** ($n = 10$) even in refluxing methylcyclohexane for 1 h.

Another optically active cyclophane *o*-**15**, which possessed an *ortho*-phenylene ansa chain, was synthesized from 1,2-benzenedialdehyde *o*-**11** (Scheme 3). The aldehyde *o*-**11** was converted to 1,2-benzenedipentanoic acid *o*-**12** by a synthetic process involving the Wittig−Horner reaction. Then, condensation with the Meldrum's acid **3** gave bis(dioxanedione) *o*-**13** in 82% yield, which was transformed into bis(dioxinone) *o*-**14** by heating in the presence of acetone. It turned out that crystalline *o*-**14** was easier to purify than *o*-**13**. The dioxinone *o*-**14** also decomposed to acylketene in refluxing chlorobenzene[9] and gave (±)-*o*-**15** in a high yield. Resolution was conducted as in the case of **1** to give (*R*)-*o*-**15** and (*S*)-*o*-**15** as configurationally stable compounds. The absolute configuration was determined by the similarity of the CD spectra to **1** (Figure 3). The corresponding meta and para derivatives, (±)-*m*-**15** and (±)-*p*-**15**, were also prepared from 1,3- and 1,4-benzenedialdehyde, *m*-**11** and *p*-**11**, respectively. However, the diastereomeric imines of *m*-**11** and *p*-**11** with (*R*)-1-phenylethylamine epimerized at room temperature.

The optically active cyclophanes **1** formed complexes with metals.[10] When (*R*)-**1** ($n = 8-10$) were treated with $Cu(OAc)_2$ in aqueous ethanol at room temperature, blue copper complexes $Cu[(R)\text{-}\mathbf{1}]_2$, (*R*,*R*)-**16** ($n = 8-10$) were obtained in quantitative yields. X-ray analyses of the (*R*,*R*)-**16** ($n = 8,9$) showed that the two carbonyl oxygens occupied the trans position, and consequently, the bridging methylenes of the two ligands were in syn relationship (Figure 4). A water molecule occupied the apical position of (*R*,*R*)−**16** ($n = 8, 9$) anti to the bridging methylene, suggesting the Lewis acid character of the copper complexes. The molecules had roughly 2-fold axis symmetry through the apical Cu−O9(water) bond. While bis(acetylacetonato)- and bis(salicylaldehydato)copper complexes were reported to exhibit the ideal square planar coordination,[11,12] (*R*,*R*)-**16** ($n = 8,9$) possessed a five-coordinate Cu atom including coordination of a water molecule. The four oxygen atoms, O1, O2, O3, and O4, were not planar and deviated in the range of −0.280 to +0.285 Å for (*R*,*R*)-**16** ($n = 8$) and −0.341 to +0.02 Å for (*R*,*R*)-**16** ($n = 9$). The geometry was not the ideal trigonal-bipyramidal either. While the axial O1−Cu−O4 angles were close to 180° (178.3° in (*R*,*R*)-**16** ($n = 8$) and 174.9° in (*R*,*R*)-**16** ($n = 9$)), the equatorial O2−Cu−O3 angles were not 120° (147.3° in (*R*,*R*)-**16** ($n = 8$) and 152.5° in (*R*,*R*)-**16** ($n = 9$)). Thus (*R*,*R*)-**16** ($n = 8, 9$) had an intermediate geometry between square-pyramidal and trigonal-bipyramidal. Such distortion may be conveniently described by the geometrical parameter τ defined as [(O1−Cu−O4) − (O2−Cu−O3)]/60, being $\tau = 0$

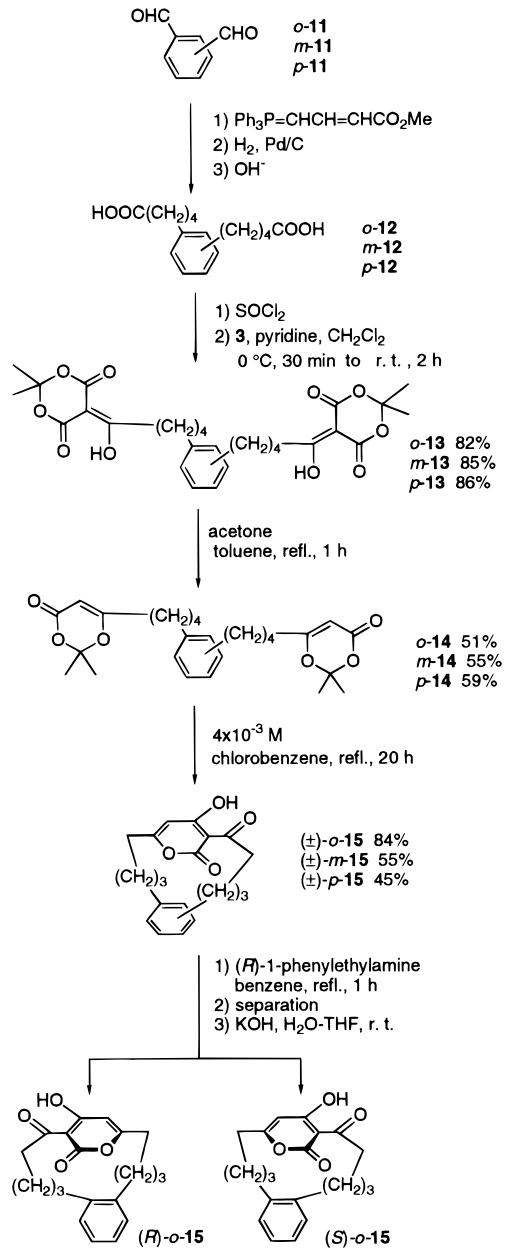
(9) Sato, M.; Ogasawara, H.; Oi, K.; Kato, T. *Chem. Pharm. Bull.* **1983**, *31*, 1896.

(10) For example, see Collie, J. N. *J. Chem. Soc.* **1891**, *59*, 617. Sitran, S.; Fregona, D.; Faraglia, G. *J. Coord. Chem.* **1990**, *22*, 229.

(11) Lebrun, P. C.; Lyon, W. D.; Kuska, H. A. *J. Crystallogr. Spectrosc. Res.* **1986**, *6*, 889.

(12) Elmali, A.; Elerman, Y.; Svoboda, I.; Fuess, H. *Z. Kristallogr.* **1995**, *210*, 612.

Scheme 3



for the ideal square-pyramidal and $\tau = 1$ for the trigonal-bipyramidal.[13] The calculated τ values were 0.42 for (*R*,*R*)-**16** ($n = 8$) and 0.37 for (*R*,*R*)-**16** ($n = 9$), implying that the geometry was distorted from the square-pyramidal toward the trigonal-bipyramidal by 42% and 37%, respectively. We consider that the distorted five-coordination reflects constraint at the Cu atom caused by the ansa chain. Imines (*R*,*R*)-**6** ($n = 9$) and (*S*,*R*)-**6** ($n = 9$) also formed copper complexes Cu[(*R*,*R*)-**6** ($n = 9$)]$_2$, (*R*,*R*,*R*,*R*)-**17** ($n = 9$), and Cu[(*S*,*R*)-**6** ($n = 9$)]$_2$, (*S*,*R*,*S*,*R*)-**17** ($n = 9$), respectively, by the treatment with Cu(OTf)$_2$ and triethylamine in THF. Notably, the physical properties of the diastereomers differed considerably. While the solution of the former complex in CH_2Cl_2 was blue (λ_{max} at 558 nm), the latter solution exhibited green color (λ_{max} at 642 nm). Europium complexes Eu[(*R*)-**1** ($n = 8-10$)]$_3$, (*R*,*R*,*R*)-**18** ($n = 8-10$) were obtained from (*R*)-**1** ($n = 8-10$) and $EuCl_3$ in the presence of 2 M KOH. The optically active europium complexes exhibited strong red fluorescence.

(13) Addison, A. W.; Rao, T. N.; Reedijk, J.; van Rijn, J.; Verschoor, G. C. *J. Chem. Soc., Dalton Trans.* **1984**, 1349.

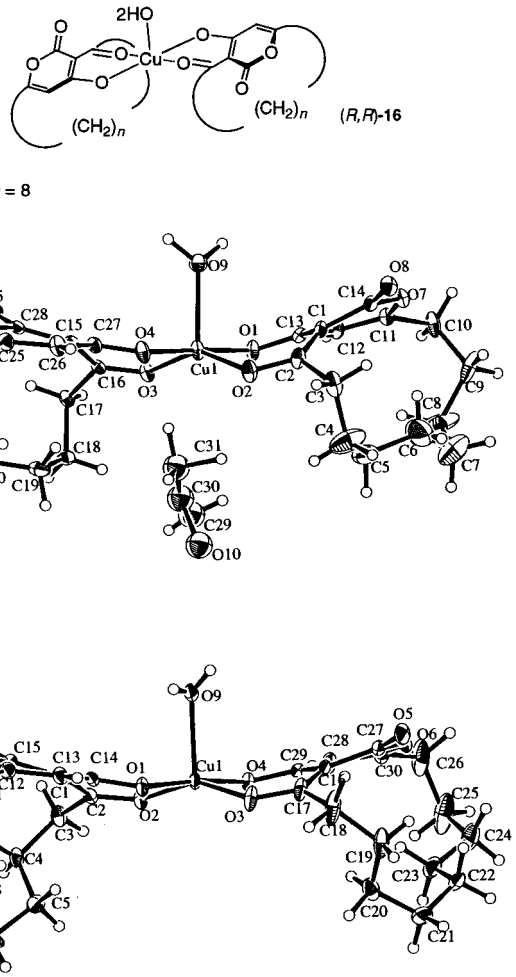


Figure 4. ORTEP drawing of (*R*,*R*)-**16** ($n = 8$)·acetone and (*R*,*R*)-**16** ($n = 9$) along with the atomic numbering scheme. Atoms of solvent are drawn at the ideal sphere for clarity. Thermal ellipsoids are drawn at the 30% probability level. Selected bond lengths (Å) and bond angles (deg) at metal atom: for (*R*,*R*)-**16** ($n = 8$), Cu−O1 = 1.912(4), Cu−O2 = 1.958(4), Cu−O3 = 1.957(4), Cu−O4 = 1.915(4), Cu−O9 = 2.213(4), O1−Cu−O4 = 178.3(2), O2−Cu−O3 = 147.3(2), O2−Cu−O9 = 104.0(2), O3−Cu−O9 = 108.7(2); for (*R*,*R*)-**16** ($n = 9$), Cu−O1 = 1.914(2), Cu−O2 = 1.948(2), Cu−O1 = 1.943(3), Cu−O1 = 1.910(2), Cu−O9 = 2.207(3), O1−Cu−O4 = 174.9(1), O2−Cu−O3 = 152.5(1), O2−Cu−O9 = 103.6(1), O3−Cu−O9 = 103.9(1).

In summary, a series of optically pure cyclophanes that can chelate metals were prepared in a few steps using convenient starting materials and reagents. The [4 + 2]cycloaddition of acylketene turned out to be a powerful method for the synthesis of cyclophanes. Various applications of chiral metal complexes derived from the cyclophanes are conceivable, which includes asymmetric catalysts, chiral stationary phases, optical, electronic, or magnetic materials.

Experimental Section

1,8-Bis(2,2-dimethyl-4,6-dioxo-1,3-dioxane-5-yl)octane-1,8-dione, 4 (*n* = 6). Under an argon atmosphere, a solution of hexanedicarboxyl dichloride **2** ($n = 6$) (11.95 g, 0.05 mol) in dichloromethane (50 mL) was added dropwise to a stirred solution of Meldrum's acid **3** (14.4 g, 0.10 mol) and pyridine (19.75 g, 0.25 mol) in dichloromethane (200 mL) under ice-cooling over 15 min. The mixture was stirred for 30 min at the temperature and then for 2 h at room temperature. The mixture was acidified with 10% hydrochloric acid, and dichloromethane was removed in vacuo. Separated crystals were filtered, washed with water, and dried. Recrystallization from a mixture of dichloromethane and ether gave yellowish needles of **4** ($n = 6$) (16.2 g, 76%). Mp 94−

98 °C. Anal. calcd for $C_{20}H_{26}O_{10}$: C, 56.32%; H, 6.15%. Found: C, 56.33%; H, 6.37%. IR ($CHCl_3$) 2941, 2861, 1735, 1662, 1570 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.47 (4H, m), 1.67 (4H, m), 1.74 (12H, s), 3.07 (4H, t, $J = 7.6$ Hz), 15.30 (2H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.9, 26.9, 29.0, 35.7, 91.3, 104.7, 159.9, 170.3, 197.6.

(±)-15-Hydroxy-13-oxabicyclo[10.2.2]tetradecane-1(15),12(16)-diene-2,14-dione, (±)-1 (*n* = 9). Under an argon atmosphere, chlorobenzene (1 L) was boiled on an oil bath until about 50 mL of chlorobenzene was distilled off. Then, a solution of **4** ($n = 9$) (4.68 g, 10 mmol) in chlorobenzene (50 mL) was added dropwise under reflux by a syringe pump for over 20 h. The solution was heated at reflux for an additional 30 min, and then the solvent was evaporated in vacuo. The residue was distilled by Kugelrohr to give (±)-**1** ($n = 9$) (2.38 g, 90%). Colorless prisms of mp 92−93 °C (hexane). Bp 122 °C/0.23 mm Hg. Anal. calcd for $C_{15}H_{20}O_4$: C, 68.18%; H, 7.58%. Found: C, 68.18%; H, 7.61%. MS (EI) *m*/*z* 264 ($\mathbf{M}^+$, 100%), 165 (92%), 69 (58%). IR ($CHCl_3$) 1733, 1633, 1557 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.68 (1H, m), 0.81 (2H, m), 1.13 (1H, m), 1.20−1.60 (8H, m), 2.01 (2H, m), 2.34 (1H, ddd, $J = 13.6$, 12.2, 6.6 Hz), 2.53 (2H, t, $J = 6.2$ Hz), 3.61 (1H, ddd, $J = 13.6$, 4.6, 4.6 Hz), 6.03 (1H, s), 14.89 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.5, 24.9, 26.6, 27.4, 27.5, 27.8, 28.0, 34.9, 41.2, 100.2, 101.3, 161.1, 173.8, 177.6, 207.6.

(±)-13-Hydroxy-11-oxabicyclo[8.2.2]tetradecane-1(13),10(14)-diene-2,12-dione, (±)-1 (*n* = 7). Colorless prisms of mp 99−100 °C (hexane). Bp 117 °C/0.27 mm Hg. Anal. calcd for $C_{13}H_{16}O_4$: C, 66.10%; H, 6.78%. Found: C, 66.02%; H, 6.81%. MS (EI) *m*/*z* 236 ($\mathbf{M}^+$, 62%), 165 (100%), 69 (62%). IR ($CHCl_3$) 1738, 1627, 1549 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.18 (1H, m), 1.00−1.40 (6H, m), 1.55 (1H, m), 2.01 (2H, m), 2.35 (1H, ddd, $J = 12.4$, 6.6, 2.2 Hz), 2.53 (1H, ddd, $J = 12.4$, 10.0, 5.6 Hz), 2.62 (1H, ddd, $J = 12.4$, 5.6, 3.8 Hz), 3.63 (1H, dt, $J = 12.4$, 3.2 Hz), 6.05 (1H, s), 13.60 (1H, br s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.4, 27.5, 29.4, 29.6, 29.8, 34.5, 39.5, 102.0, 102.5, 162.1, 175.5, 176.2, 204.2.

(±)-14-Hydroxy-12-oxabicyclo[9.2.2]pentadecane-1(14),11(15)-diene-2,13-dione, (±)-1 (*n* = 8). Colorless prisms of mp 41−42 °C (pentane). Bp 115 °C/0.35 mm Hg. Anal. calcd for $C_{14}H_{18}O_4$: C, 67.17%; H, 7.25%. Found: C, 66.91%; H, 7.34%. MS (EI) *m*/*z* 250 ($\mathbf{M}^+$, 43%), 165 (100%), 69 (60%). IR (neat) 1738, 1631, 1555 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.81 (1H, m), 1.02 (2H, m), 1.13 (3H, m), 1.34 (2H, m), 1.61 (1H, m), 1.70−1.90 (3H, m), 2.34 (1H, ddd, $J = 13.2$, 8.0, 5.6 Hz), 2.43 (1H, ddd, $J = 13.2$, 6.6, 6.6 Hz), 2.68 (1H, ddd, $J = 13.2$, 5.6, 5.6 Hz), 3.59 (1H, ddd, $J = 13.2$, 8.1, 5.1 Hz), 6.03 (1H, s), 14.11 (1H, br s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.2, 25.8, 26.1, 26.8, 27.1, 29.6, 34.0, 37.6, 101.8, 103.6, 161.8, 173.8, 175.9, 206.0.

(±)-16-Hydroxy-14-oxabicyclo[11.2.2]heptadecane-1(16),13(17)-diene-2,15-dione, (±)-1 (*n* = 10). Colorless prisms of mp 73−75 °C (pentane). Bp 130 °C/0.30 mm Hg. Anal. calcd for $C_{16}H_{22}O_4$: C, 69.06%; H, 7.91%. Found: C, 68.81%; H, 7.97%. MS (EI) *m*/*z* 278 ($\mathbf{M}^+$, 80%), 165 (73%), 69 (60%). IR ($CHCl_3$) 1724, 1636, 1555 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.96−1.21 (10H, m), 1.36 (1H, m), 1.52 (1H, m), 1.76 (4H, m), 2.34 (2H, ddd, $J = 13.6$, 11.2, 4.8 Hz), 2.67 (1H, ddd, $J = 13.6$, 4.8, 4.8 Hz), 4.00 (1H, ddd, $J = 12.4$, 11.2, 4.8 Hz), 5.99 (1H, s), 16.02 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.9, 25.7, 27.1, 27.2, 27.4, 27.4, 28.8, 29.2, 34.8, 36.7, 101.9, 102.4, 161.4, 172.5, 178.8, 209.0.

(±)-17-Hydroxy-15-oxabicyclo[12.2.2]octadecane-1(17),14(18)-diene-2,16-dione, (±)-1 (*n* = 11). Colorless prisms of mp 77−78 °C (pentane). Bp 126 °C/0.23 mm Hg. Anal. calcd for $C_{17}H_{24}O_4$: C, 69.86%; H, 8.22%. Found: C, 69.85%; H, 8.22%. MS (EI) *m*/*z* 292 ($\mathbf{M}^+$, 100%), 181 (47%), 165 (60%). IR ($CHCl_3$) 1731, 1636, 1556 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.00 (4H, m), 1.10−1.40 (10H, m), 1.61 (2H, m), 1.89 (2H, m), 2.31 (2H, m), 2.70 (1H, ddd, $J = 13.6$, 6.0, 3.6 Hz), 3.87 (1H, ddd, $J = 11.6$, 7.6, 4.4 Hz), 5.97 (1H, s), 16.32 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 24.9, 26.0, 26.2, 27.1, 27.2, 27.4, 27.8, 28.0, 34.7, 40.5, 100.0, 102.1, 160.9, 172.5, 179.7, 208.9.

(±)-18-Hydroxy-16-oxabicyclo[13.2.2]nonadecane-1(18),15(19)-diene-2,17-dione, (±)-1 (*n* = 12). Purified by column chromatography on neutral silica gel (Silica Gel 60 N, 40−100 μm, Kanto Chemical CO., INC.) using hexane/ethyl acetate (10:1) as an eluent. Colorless prisms of mp 62−65 °C (pentane). Anal. calcd for $C_{18}H_{26}O_4$: C, 70.54%; H, 8.56%. Found: C, 70.15%; H, 8.52%. MS (EI) *m*/*z* 306 ($\mathbf{M}^+$, 100%), 288 (33%), 181 (48%), 69 (45%). IR ($CHCl_3$) 1731, 1637, 1557 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.00−1.40 (18H, m), 1.76 (4H, m), 2.50 (2H, m), 5.97 (1H, s), 16.84 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.5, 26.0, 26.9, 27.5, 27.6, 27.7, 28.3, 28.6, 28.7, 29.2, 34.7, 39.5, 100.2, 102.0, 160.9, 172.3, 180.7, 209.4.

(±)-22-Hydroxy-20-oxabicyclo[17.2.2]tricosane-1(22),19(23)-diene-2,21-dione, (±)-1 (*n* = 16). Purified by column chromatography on neutral silica gel (Silica Gel 60 N, 40−100 μm, Kanto Chemical CO., INC.) using hexane/ethyl acetate (10:1) as an eluent. Yellowish oil. MS (EI) *m*/*z* 362 ($\mathbf{M}^+$, 95%), 181 (56%), 69 (63%). High-resolution MS *m*/*z* ($\mathbf{M}^+$) calcd $C_{22}H_{34}O_4$: 362.2455. Found: 362.2439. IR (neat) 1742, 1636, 1556 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.20−1.35 (22H, m), 1.34 (2H, m), 1.69 (4H, m), 2.53 (2H, dd, $J = 6.4$, 6.4 Hz), 3.05 (2H, t, $J = 7.2$ Hz), 5.93 (1H, s), 16.99 (1H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.0, 26.1, 27.3, 27.7, 28.0, 28.1, 28.1, 28.2, 28.3, 28.3, 28.5, 29.0, 29.1, 29.2, 34.2, 40.8, 99.4, 101.5, 160.5, 172.5, 181.3, 208.6.

General Procedures for the Preparation of Imine (*R*,*R*)-6 and (*S*,*R*)-6. Under an argon atmosphere, a solution of (±)-**1** (5.0 mmol) and (*R*)-1-phenylethylamine (5.0 mmol) in benzene (30 mL) was refluxed for 1 h. After evaporation of the solvent, the residue was purified by column chromatography on neutral silica gel using hexane/ethyl acetate (5:1) as an eluent to give first (*R*,*R*)-**6** and then (*S*,*R*)-**6** as crystals. (*R*,*R*)-**6** ($n = 7$) and (*S*,*R*)-**6** ($n = 7$) were separated by TLC over silica gel using chloroform as a developing solvent.

(*R*,*R*)- and (*S*,*R*)-2-[1-(Phenylethyl)amino]-11-oxabicyclo[8.2.2]-tetradecane-1(2),10(14)-diene-12,13-dione, (*R*,*R*)-6 (*n* = 7) and (*S*,*R*)-6 (*n* = 7). (*R*,*R*)-**6** ($n = 7$): Colorless prisms of mp 161−162 °C (hexane-dichloromethane). Anal. calcd for $C_{21}H_{25}NO_3$: C, 74.30%; H, 7.43%; N, 4.13%. Found: C, 74.05%; H, 7.14%; N, 4.06%. MS (EI) *m*/*z* 339 ($\mathbf{M}^+$, 39%), 234 (8%), 105 (100%). IR (neat) 1708, 1639, 1580 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.90 (1H, m), 1.07 (1H, m), 1.21 (1H, m), 1.45 (5H, m), 1.64 (3H, d, $J = 6.8$ Hz), 1.92 (2H, m), 2.44 (3H, m), 3.66 (1H, m), 4.76 (1H, dq, $J = 7.0$, 6.8 Hz), 5.79 (1H, s), 7.31 (5H, m), 11.96 (1H, br s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.4, 27.0, 27.3, 27.9, 28.2, 29.5, 29.7, 33.8, 53.8, 99.0, 109.0, 125.4, 127.8, 129.0, 141.8, 164.7, 169.0, 173.0, 182.5. $[\alpha]^{24}_D$ −34.1 (*c* 1, $CHCl_3$). CD (0.034 mM, CH_3CN) 274.4 nm ($\Delta\epsilon = +28.63$), 252.4 ($\Delta\epsilon = -2.85$), 240.6 ($\Delta\epsilon = +4.95$), 219.2 ($\Delta\epsilon = -9.79$). (*S*,*R*)-**6** ($n = 7$). Colorless prisms of mp 144−145 °C (hexane-dichloromethane). Anal. calcd for $C_{21}H_{25}NO_3$: C, 74.30%; H, 7.43%; N, 4.13%. Found: C, 74.02%; H, 7.31%; N, 4.11%. MS (EI) *m*/*z* 339 ($\mathbf{M}^+$, 38%), 234 (7%), 105 (100%). IR (neat) 1706, 1639, 1578 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.47 (1H, m), 0.75 (2H, m), 1.20−1.60 (6H, m), 1.67 (3H, d, $J = 6.8$ Hz), 1.87 (1H, m), 2.41 (2H, m), 2.58 (1H, m), 3.75 (1H, m), 4.91 (1H, dq, $J = 7.6$, 6.8 Hz), 5.79 (1H, s), 7.34 (5H, m), 12.09 (1H, br s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.9, 26.4, 27.0, 27.5, 28.0, 29.1, 29.2, 33.8, 54.4, 99.1, 109.0, 125.4, 127.7, 129.0, 141.9, 164.8, 169.0, 172.9, 182.2. $[\alpha]^{22}_D$ −80.2 (c 1, $CHCl_3$). CD (0.035 mM, CH_3CN) 276.2 nm ($\Delta\epsilon = -29.39$), 251.0 ($\Delta\epsilon = +15.75$), 231.4 ($\Delta\epsilon = +12.18$), 214.6 ($\Delta\epsilon = -12.47$).

General Procedures for the Preparation of (*R*)- and (*S*)-1 by Hydrolysis. A solution of (*R*,*R*)-**6** or (*S*,*R*)-**6** (1.0 mmol) and KOH (225 mg, 4.0 mmol) in THF (5 mL)-H_2O (5 mL) was stirred for 20 h (2 h in case of (*R*,*R*)-**6** ($n = 7$) or (*S*,*R*)-**6** ($n = 7$)) at room temperature. The mixture was acidified with 10% hydrochloric acid and then extracted with ether. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated. The residue was purified by column chromatography on neutral silica gel using hexane/ethyl acetate (10:1) as an eluent to give (*R*)-**1** or (*S*)-**1** as crystals. The optical purity was determined to be >99% by chiral HPLC analysis using Chiralcel OD (hexane/2-propanol/trifluoroacetic acid = 99:1:1). (*R*)-**1** ($n = 7$): colorless needles of mp 89−91 °C (pentane). $[\alpha]^{23}_D$ −290.9 (*c* 1, $CHCl_3$). CD (0.082 mM, hexane) 326.6 nm ($\Delta\epsilon = -9.46$), 260.8 ($\Delta\epsilon = +16.31$), 237.4 ($\Delta\epsilon = -19.84$). (*S*)-**1** ($n = 7$): yield, 92%. Colorless needles of mp 86−88 °C (pentane). $[\alpha]^{24}_D$ +281.1 (*c* 1, $CHCl_3$). CD (0.084 mM, hexane) 327.8 nm ($\Delta\epsilon = +10.20$), 260.4 ($\Delta\epsilon = -18.44$), 237.4 ($\Delta\epsilon = +21.51$). (*R*)-**1** ($n = 8$): colorless needles of mp 74−75 °C (pentane). $[\alpha]^{22}_D$ −250.6 (*c* 1, $CHCl_3$). CD (0.072 mM, hexane)

325.0 nm ($\Delta\epsilon = -11.31$), 256.2 ($\Delta\epsilon = +20.23$), 235.2 ($\Delta\epsilon = -19.76$) 219.0 ($\Delta\epsilon = +1.45$), 213.0 ($\Delta\epsilon = -0.84$). (*S*)-**1** ($n = 8$): colorless needles of mp 75−76 °C (pentane). $[\alpha]^{21}_D$ +252.2 (*c* 1, $CHCl_3$). CD (0.077 mM, hexane) 325.0 nm ($\Delta\epsilon = +12.72$), 256.0 ($\Delta\epsilon = -19.89$), 235.8 ($\Delta\epsilon = +22.36$) 219.6 ($\Delta\epsilon = +0.64$), 213.6 ($\Delta\epsilon = +2.84$). (*R*)-**1** ($n = 9$): colorless oil. $[\alpha]^{24}_D$ −194.2 (*c* 1, $CHCl_3$). CD (0.076 mM, hexane) 325.6 nm ($\Delta\epsilon = -10.02$), 254.6 ($\Delta\epsilon = +18.80$), 232.4 ($\Delta\epsilon = -28.62$), 215.8 ($\Delta\epsilon = +1.17$). (*S*)-**1** ($n = 9$): colorless oil. $[\alpha]^{24}_D$ +186.6 (*c* 1, $CHCl_3$). CD (0.074 mM, hexane) 324.4 nm ($\Delta\epsilon = +9.95$), 255.2 ($\Delta\epsilon = -19.46$), 232.6 ($\Delta\epsilon = +28.25$), 216.4 ($\Delta\epsilon = -1.76$). (*R*)-**1** ($n = 10$): colorless needles of mp 54−56 °C (pentane). $[\alpha]^{23}_D$ −95.1 (c 1, $CHCl_3$). CD (0.061 mM, hexane) 324.2 nm ($\Delta\epsilon = -6.33$), 253.2 ($\Delta\epsilon = +17.71$), 230.8 ($\Delta\epsilon = -15.12$). (*S*)-**1** ($n = 10$): colorless needles of mp 57−61 °C (pentane). $[\alpha]^{22}_D$ +95.1 (*c* 1, $CHCl_3$). CD (0.067 mM, hexane) 324.6 nm ($\Delta\epsilon = +7.46$), 254.0 ($\Delta\epsilon = -18.43$), 230.4 ($\Delta\epsilon = +17.30$).

1,2-Bis[4-(2,2-dimethyl-4,6-dioxo-1,3-dioxan-5-yl)-5-oxopentyl]-benzene, *o*-13. Under an argon atmosphere, a solution of 1,2-benzenedipentanoic acid (0.60 g, 2.16 mmol) in $SOCl_2$ (10 mL) was refluxed for 3 h. After removal of $SOCl_2$ in vacuo, the redisue was diluted with dichloromethane (5 mL). The solution was then added dropwise to a stirred solution of Meldrum's acid (**3**, 0.60 g, 4.2 mmol) and pyridine (1.58 g, 20 mmol) in dichloromethane (15 mL) under ice-cooling over 15 min. The mixture was stirred for 30 min at the temperature and then for 2 h at room temperature. After being acidified with 10% hydrochloric acid, the organic materials were extracted with chloroform. The organic layer was dried over $MgSO_4$ and concentrated. The residue was purified by column chromatography on neutral silica gel using chloroform as an eluent giving *o*-**13** (0.94 g, 82%) as yellowish oil. MS (FAB) *m*/*z* 531 ($\mathbf{M}^+ + 1$). IR ($CHCl_3$) 2940, 2865, 1740, 1665, 1576 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.60−1.82 (8H, m), 1.73 (12H, s), 2.66 (4H, t, $J = 8.0$ Hz), 3.13 (4H, t, $J = 8.0$ Hz), 7.13 (4H, s), 15.32 (2H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.1, 26.9, 30.9, 32.3, 35.7, 91.3, 104.8, 126.0, 129.0, 139.4, 160.0, 170.3, 197.5.

1,2-Bis[4-(2,2-dimethyl-4-oxo-4*H*-1,3-dioxin-6-yl)butyl]benzene, *o*-14. A solution of *o*-**13** (940 mg, 1.77 mmol) and dry acetone (0.5 mL, 6.80 mmol) in toluene (20 mL) was heated at reflux for 1 h. After evaporation of the solvent, the residue was purified by silica gel column chromatography using hexane/ethyl acetate (3:1) as an eluent to give *o*-**14** (400 mg, 51%) as colorless prisms. Mp 59−60 °C (ether). Anal. calcd for $C_{26}H_{34}O_6$: C, 70.56%; H, 7.74%. Found: C, 70.38%; H, 7.85%. IR ($CHCl_3$) 2999, 2940, 1730, 1632, 1490 cm^{-1}. High-resolution MS *m*/*z* calcd for $C_{26}H_{34}O_6$ ($\mathbf{M}^+$): 442.2355. Found: 442.2362. ^1H NMR (400 MHz, $CDCl_3$) δ 1.61−1.66 (8H, m), 1.67 (12H, s), 2.26 (4H, t, $J = 6.8$ Hz), 2.62 (4H, t, $J = 7.2$ Hz), 5.23 (2H, s), 7.10−7.16 (4H, m). ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.2, 25.8, 30.6, 32.4, 33.6, 93.3, 106.3, 126.1, 129.1, 139.3, 161.1, 171.4.

(±)-7,8-Benzo-16-hydroxy-14-oxabicyclo[11.2.2]heptadecane-1(16),7,13(17)-triene-2,15-dione, (±)-*o*-15. To refluxing chlorobenzene (500 mL) was added a solution of *o*-**14** (1.23 g, 2.8 mmol) in chlorobenzene (10 mL) dropwise by syringe pump over 24 h under an argon atmosphere. After being heated at reflux for an additional 30 min, the solvent was evaporated in vacuo. The residue was purified by column chromatography on neutral silica gel using chloroform as an eluent giving (±)-*o*-**15** (0.77 g, 84%) as colorless prisms. Mp 95−96 °C (ether). Anal. calcd for $C_{20}H_{22}O_4$: C, 73.60%; H, 6.79%. Found: C, 73.78%; H, 6.87%. High-resolution MS *m*/*z* calcd for $C_{20}H_{22}O_4$ ($\mathbf{M}^+$): 326.1518. Found: 326.1506. IR ($CHCl_3$) 3019, 2938, 1730, 1635, 1556 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.07 (1H, m), 1.38−1.60 (3H, m), 1.73−2.10 (5H, m), 2.17−2.61 (5H, m), 2.85 (1H, dt, $J = 13.6$, 4.4 Hz), 3.86 (1H, ddd, $J = 13.6$, 8.0, 5.6 Hz), 5.98 (1H, s), 7.05−7.12 (4H, m), 15.46 (1H, br s). ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.2, 27.4, 27.6, 30.1, 32.0, 32.7, 34.7, 38.2, 101.7, 102.4, 126.0, 126.1, 126.6, 130.0, 138.5, 140.4, 161.2, 172.4, 178.2, 207.7.

Imines of *o*-15. Under an argon atmosphere, a solution of (±)-*o*-**15** (32.6 mg, 0.10 mmol) and (*R*)-1-phenylethylamine (0.038 mL, 0.3 mmol) in benzene (15 mL) was heated at reflux for 1 h. After evaporation of the solvent, the residue was purified by column chromatography on neutral silica gel using hexane/ethyl acetate (4:1) as an eluent to give first (*R*,*R*)-imine (20 mg, 47%) and then (*S*,*R*)-imine (19 mg, 46%). (*R*,*R*)-Imine: colorless prisms of mp 124−126 °C (hexane-dichloromethane). Anal. calcd for $C_{28}H_{31}NO_3$: C, 78.29%; H, 7.27%; N, 3.26%. Found: C, 78.18%; H, 7.33%; N, 3.14%. High-resolution MS *m*/*z* calcd for $C_{28}H_{31}NO_3$ ($\mathbf{M}^+$): 429.2304. Found: 429.2305. IR ($CHCl_3$) 1696, 1650, 1574 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.88 (1H, m), 1.24−1.60 (3H, m), 1.63 (3H, d, $J = 6.8$ Hz), 1.65−2.11 (5H, m), 2.27 (1H, m), 2.42−2.58 (4H, m), 2.71 (1H, m), 3.71 (1H, m), 4.90 (1H, dq, $J = 6.8$, 6.8 Hz), 5.72 (1H, s), 7.05−7.13 (4H, m), 7.23 (5H, m), 13.77 (1H, brs). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.3, 26.0, 27.4, 27.8, 28.6, 29.9, 32.8, 33.8, 33.9, 54.6, 97.5, 108.9, 125.5, 125.9, 126.1, 127.9, 128.0, 129.2. 129.4, 139.6, 140.2, 141.7, 163.9, 165.7, 176.5, 183.1. $[\alpha]^{24}_D$ −26.6 (*c* 1, $CHCl_3$). CD (0.035 mM, CH_3CN) 335.2 nm ($\Delta\epsilon = -12.61$), 269.4 ($\Delta\epsilon = +14.75$), 222.4 ($\Delta\epsilon = -5.05$). (*S*,*R*)-Imine: colorless prisms of mp 174−175 °C (hexane-dichloromethane). Anal. calcd for $C_{28}H_{31}NO_3$: C, 78.29%; H, 7.27%; N, 3.26%. Found: C, 78.32%; H, 7.30%; N, 3.29%. High-resolution MS *m*/*z* calcd for $C_{28}H_{31}NO_3$ ($\mathbf{M}^+$): 429.2304. Found: 429.2291. IR ($CHCl_3$) 1695, 1649, 1594, 1573 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.70 (1H, m), 0.76−0.90 (2H, m), 1.19−1.36 (2H, m), 1.39−1.50 (1H, m), 1.60 (3H, d, $J = 7.0$ Hz), 1.60−1.72 (1H, m), 1.79−2.02 (3H, m), 2.13−2.32 (3H, m), 2.45 (1H, m), 2.71 (1H, m), 3.83 (1H, m), 5.00 (1H, dq, $J = 7.0$, 7.0 Hz), 5.72 (1H, s), 6.75 (1H, m), 7.01−7.31 (8H, m), 13.77 (1H, brs). ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.9, 25.9, 27.2, 27.5, 28.9, 29.5, 29.9, 32.9, 33.3, 33.7, 54.9, 97.6, 108.9, 125.7, 125.8, 127.8, 127.9, 129.2, 129.4, 139.4, 140.2, 141.6, 163.9, 165.7, 176.6, 182.8. $[\alpha]^{24}_D$ −48.4 (*c* 1, $CHCl_3$). CD (0.035 mM, CH_3CN) 334.8 nm ($\Delta\epsilon = +6.11$), 271.8 ($\Delta\epsilon = -21.00$), 225.8 ($\Delta\epsilon = +13.35$), 214.0 ($\Delta\epsilon = -3.65$).

(*R*)- and (*S*)-*o*-15. A solution of (*R*,*R*)-imine (429 mg, 1.0 mmol) and KOH (225 mg, 4.0 mmol) in THF (5 mL)-H_2O (5 mL) was stirred for 20 h at room temperature. The mixture was acidified with 10% hydrochloric acid and then extracted with ether. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated. The residue was purified by column chromatography on neutral silica gel using chloroform as an eluent to give (*R*)-*o*-**15** (323 mg, 99%). Colorless prisms of mp 100−102 °C (ether). $[\alpha]^{24}_D$ −107.4 (*c* 1, $CHCl_3$). CD (0.050 mM, CH_3CN) 322.6 nm ($\Delta\epsilon = -12.95$), 256.0 ($\Delta\epsilon = +25.96$), 232.4 ($\Delta\epsilon = -28.93$), 204.0 ($\Delta\epsilon = +9.47$). (*S*)-*o*-**15** was obtained from (*S*,*R*)-imine in 92% yield. Colorless prisms of mp 103−105 °C (ether). $[\alpha]^{24}_D$ +106.2 (*c* 1, $CHCl_3$). CD (0.050 mM, CH_3CN) 324.2 nm ($\Delta\epsilon = +14.30$), 256.2 ($\Delta\epsilon = -29.51$), 231.8 ($\Delta\epsilon = +32.00$), 205.0 ($\Delta\epsilon = -12.71$).

Cu[(*R*)-1 (*n* =8)]$_2$, (*R*,*R*)-16 (*n* = 8). $Cu(OAc)_2 \cdot H_2O$ (134 mg, 0.67 mmol) in 50% aqueous ethanol (2 mL) was added to (*R*)-**1** ($n = 8$) (335 mg, 1.35 mmol) in 75% aqueous ethanol (10 mL), and the resulting mixture was stirred at room temperature for 3 h. Then, the solvents were evaporated in vacuo, and the residue was washed with water and hexane. Recrystallization from chloroform−ether gave (*R*,*R*)-**16** ($n = 8$) (364 mg, 98%). Blue prisms, mp >255 °C (dec). Anal. calcd for $C_{28}H_{34}CuO_8$: C, 59.83%; H, 6.10%. Found: C, 59.59%; H, 6.14%. MS (FAB) *m*/*z* 561 for ^{63}Cu[(*R*)-**1** ($n = 8$)]$_2$, 563 for ^{65}Cu[(*R*)-**1** ($n = 8$)]$_2$. IR ($CHCl_3$) 3019, 2936, 1711, 1635, 1560 cm^{-1}. $[\alpha]_D^{24}$ +34.8 (*c* 0.1, $CHCl_3$). UV (MeOH) λ_{max} (ϵ) 666 nm (70), 310 (24900), 244 (41500). CD (0.02 mM, MeOH) 683.2 nm ($\Delta\epsilon = -0.24$), 322.0 ($\Delta\epsilon = -17.71$), 274.0 ($\Delta\epsilon = +52.64$), 241.4 ($\Delta\epsilon = -39.6$).

Cu[(*R*)-1 (*n* = 9)]$_2$, (*R*,*R*)-16 (*n* = 9). Prepared from (*R*)-**1** ($n = 9$) (132 mg, 0.50 mmol) and $Cu(OAc)_2 \cdot H_2O$ (49.9 mg, 0.25 mmol) in 94% yield (138 mg) as blue prisms. Mp 243−255 °C (dec) (acetone−H_2O). Anal. calcd for $C_{30}H_{38}CuO_8$: C, 61.05%; H, 6.49%. Found: C, 60.90%; H, 6.51%. MS (FAB) *m*/*z* 589 for ^{63}Cu[(*R*)-**1** ($n = 9$)]$_2$, 591 for ^{65}Cu[(*R*)-**1** ($n = 9$)]$_2$. IR ($CHCl_3$) 3019, 2932, 1713, 1637, 1556 cm^{-1}. $[\alpha]_D^{24}$ +29.8 (*c* 0.1, $CHCl_3$). UV (MeOH) λ_{max} (ϵ) 656.0 (58), 303 (24300), 239 (43100). CD (0.02 mM, MeOH) 672.0 nm ($\Delta\epsilon = -0.25$), 316.4 ($\Delta\epsilon = -17.2$), 275.4 ($\Delta\epsilon = 50.2$), 240.8 ($\Delta\epsilon = -46.3$).

Cu[(*R*)-1 (*n* = 10)]$_2$, (*R*,*R*)-16 (*n* = 10). Prepared from (*R*)-**1** ($n = 10$) (214 mg, 0.77 mmol) and $Cu(OAc)_2 \cdot H_2O$ (76.8 mg, 0.38 mmol) in 96% yield (246 mg) as blue needles. Mp >255 °C (dec) (acetone-H_2O). Anal. calcd for $C_{32}H_{42}CuO_8$: C, 62.17%; H, 6.65%. Found: C, 62.04%; H, 6.65%. MS (FAB) *m*/*z* 617 for ^{63}Cu[(*R*)-**1** ($n = 10$)]$_2$, 619 for ^{65}Cu[(*R*)-**1** ($n = 10$)]$_2$. IR ($CHCl_3$) 3018, 2932, 1713, 1641, 1555 cm^{-1}. $[\alpha]_D^{24}$ +49.8 (*c* 0.1, $CHCl_3$). UV (MeOH) λ_{max} (ϵ) 654 (40),

304 (28000), 238 (48700). CD (0.02 mM, MeOH) 671.0 nm ($\Delta\epsilon$ = −0.26), 315.8 ($\Delta\epsilon$ = −7.12), 274.2 ($\Delta\epsilon$ = +38.1), 238.8 ($\Delta\epsilon$ = −31.2).

Cu[(*R,R*)-6 (*n* = 9)]$_2$, (*R,R,R,R*)-17 (*n* = 9). A solution of (*R,R*)-**6** (141 mg, 0.40 mmol) and Et_3N (0.058 mL, 0.4 mmol) in THF (2 mL) was added to a stirred solution of copper (II) trifluoromethanesulfonate (72.4 mg, 0.20 mmol) in THF (2 mL) under an argon atmosphere. Stirring was continued at room temperature for 12 h and then at 50 °C for 12 h. After evaporation of the solvent, the residue was washed with water and dried in vacuo, giving the copper complex (157 mg, 99%) as a dark blue amorphous solid. Mp 150−160 °C (dec). Anal. calcd for $C_{46}H_{56}CuN_2O_6$: C; 69.37%, H; 7.09%, N; 3.52%. Found: C; 69.33%, H; 7.25%, N; 3.45%. MS (FAB) *m*/*z* 793 for ^{63}Cu[(*R,R*)-**6** (*n* = 9)]$_2$+1, 795 for ^{65}Cu[(*R,R*)-**6** (*n* = 9)]$_2$+1. IR (CH_2Cl_2) 1693, 1641, 1572 cm^{-1}. $[\alpha]^{24}_D$ −44 (*c* 0.05, CH_2Cl_2). UV (CH_2Cl_2) λ_{max} (ϵ) 558 nm (130), 324 (25900), 248 (21700). CD (0.02 mM, CH_2Cl_2) 700 nm ($\Delta\epsilon$ = +0.50), 556.0 ($\Delta\epsilon$ = −2.09), 428.5 ($\Delta\epsilon$ = −0.36), 336.5 ($\Delta\epsilon$ = −9.71), 270.5 ($\Delta\epsilon$ = +55.16), 247.0 ($\Delta\epsilon$ = −18.0).

Cu[(*S,R*)-16 (*n* = 9)]$_2$, (*S,R,S,R*)-17 (*n* = 9). Yield, 100%. Dark green needles of mp 230−235 °C (dec) (dichloromethane-hexane). Anal. calcd for $C_{46}H_{56}CuN_2O_6$: C, 69.37%; H, 7.09%; N, 3.52%. Found: C, 69.29%; H, 7.14%; N, 3.48%. MS (FAB) *m*/*z* 793 for ^{63}Cu[(*S,R*)-**16** (*n* = 9)]$_2$+1, 795 for ^{65}Cu[(*S,R*)-**16** (*n* = 9)]$_2$+1. IR (CH_2Cl_2) 1689, 1642, 1565 cm^{-1}. $[\alpha]^{24}_D$ −396 (*c* 0.05, CH_2Cl_2). UV (CH_2Cl_2) λ_{max} (ϵ) 642 nm (280), 326 (21200), 250 (12000). CD (0.02 mM, CH_2Cl_2) 752 nm ($\Delta\epsilon$ = −0.50), 597.0 ($\Delta\epsilon$ = +2.65), 437.0 ($\Delta\epsilon$ = +1.02), 307.5 ($\Delta\epsilon$ = −37.7), 278.5 ($\Delta\epsilon$ = −55.45).

Eu[(*R*)-1 (*n* =8)]$_3$, (*R,R,R*)-18 (*n* = 8). To (*R*)-**1** (*n* = 8) (150 mg, 0.60 mmol) in 50% aqueous ethanol (6 mL) was added 2 M KOH (0.30 mL, 0.60 mmol), and the mixture was stirred for 0.5 h. Then, $EuCl_3 \cdot 6H_2O$ (73.2 mg, 0.20 mmol) was added. Stirring was continued at room temperature for 1 day and then at 50 °C for 1 day. After evaporation of the solvent, the residue was washed with water and hexane, and dried in vacuo giving (*R,R,R*)-**18** (*n* = 8) (144 mg, 80%) as colorless amorphous. Anal. calcd for $C_{42}H_{51}EuO_{12}$: C, 56.06%; H, 5.71%. Found: C, 56.66%; H, 5.33%. MS (FAB) *m*/*z* 898 for ^{151}Eu[(*R*)-**1** (*n* =8)]$_3$, 900 for ^{153}Eu[(*R*)-**1** (*n* =8)]$_3$. IR ($CHCl_3$) 3019, 2936, 1698, 1639, 1587, 1420 cm^{-1}. $[\alpha]_D^{24}$ +105.4 (*c* 1, $CHCl_3$). CD (0.012 mM, MeOH) 312.8 nm ($\Delta\epsilon$ = −31.92), 262.8 ($\Delta\epsilon$ = +129.3), 245.2 ($\Delta\epsilon$ = −57.76), 225.6 ($\Delta\epsilon$ = +20.04).

Eu[(*R*)-1 (*n* =9)]$_3$, (*R,R,R*)-18 (*n* = 9). Prepared from (*R*)-**1** (*n* = 9) (106 mg, 0.40 mmol) and $EuCl_3 \cdot 6H_2O$ (48.7 mg, 0.13 mmol) in 98% yield (120 mg) as colorless amorphous. Anal. calcd for $C_{45}H_{57}EuO_{12}$: C, 57.38%; H, 6.10%. Found: C, 57.35%; H, 6.10%. MS (FAB) *m*/*z* 940 for ^{151}Eu[(*R*)-**1** (*n* =9)]$_3$, 942 for ^{153}Eu[(*R*)-**1** (*n* = 9)]$_3$. IR ($CHCl_3$) 3020, 2930, 1683, 1642, 1586, 1423 cm^{-1}. $[\alpha]_D^{24}$ +72.0 (*c* 1, $CHCl_3$). CD (0.02 mM, MeOH) 310.2 nm ($\Delta\epsilon$ = −20.13), 262.8 ($\Delta\epsilon$ = +96.26), 243.0 ($\Delta\epsilon$ = −44.8), 224.2 ($\Delta\epsilon$ = +6.95).

Eu[(*R*)-1 (*n* =10)]$_3$, (*R,R,R*)-18 (*n* = 10). Obtained from (*R*)-**1** (*n* = 10) (83.4 mg, 0.30 mmol) and $EuCl_3 \cdot 6H_2O$ (36.6 mg, 0.10 mmol) in 90% yield (88.2 mg) as colorless needles. Mp 210−225 (dec) (ethanol-H_2O). Anal. calcd for $C_{48}H_{63}EuO_{12}$: C, 58.59%; H, 6.45%. Found: C, 57.92%; H, 6.48%. MS (FAB) *m*/*z* 982 for ^{151}Eu[(*R*)-**1** (*n* = 10)]$_3$, 984 for ^{153}Eu[(*R*)-**1** (*n* = 10)]$_3$. IR ($CHCl_3$) 3020, 2931, 1677, 1646, 1587, 1421 cm^{-1}. $[\alpha]_D^{24}$ +125.2 (*c* 1, $CHCl_3$). CD (0.012 mM, MeOH) 310.2 nm ($\Delta\epsilon$ = −13.13), 261.6 ($\Delta\epsilon$ = +93.42), 241.4 ($\Delta\epsilon$ = −31.54), 223.4 ($\Delta\epsilon$ = +6.82).

X-ray Crystallography. Crystal data, data collection, and refinement for the compounds of (*R,R*)-**6** (*n* = 10), (*R,R*)-**16** (*n* = 8), and (*R,R*)-**16** (*n* = 9) are summarized in Table 2. X-ray diffraction measurements were made on a Rigaku AFC5R diffractometer using graphite monochromated *Mo*−*K*α radiation (λ =0.71069 Å). The latter two crystals of Cu complex were coated with epoxy resins and treated at low temperature (150 K). All data were corrected for Lorenz and polarization effects, and the empirical ψ scan absorption correction was applied. The structures were solved by direct methods and refined using full-matrix least squares. All nonhydrogen atoms were refined anisotropically. At this stage, the difference Fourier map for the (*R,R*)-**16** (*n* = 8) indicated that acetone molecules were included in the crystal, the position of which was refined anisotropically. The acetone molecule was included into a cavity formed by the two bridging methylenes (see Figure 4). Large temperature factors suggest disorder or insufficient content of the acetone molecule. Treatment of hydrogen atoms was made on the basis of the peak appearance in the D-map. For (*R,R*)-**6** (*n* = 10), since no peaks appeared in geometrically reasonable positions, positions for hydrogen atoms were calculated and fixed in the refinement. For (*R,R*)-**16** (*n* = 8), about half of the hydrogen atoms were found. The starting positions therefore were calculated, and the damped refinement was applied to give some changes of the model. Finally it was refined without damping, and hydrogen atoms were fixed. For (*R,R*)-**16** (*n* = 9), since all positions were found from the D-map, hydrogen atoms were refined in the normal way. The function minimized in the refinement was $\Sigma w (|F_o| - |F_c|)^2$. The weighting scheme was based on counting statistics and included a factor to downweight the intense reflections (*p* factor). All calculations were carried out using teXsan software package (Crystal Structure Analysis Package, Molecular Structure Corporation, 1985 & 1992). Further experimental details and tables of atomic coordinates, bond lengths, and angles are given as Supporting Information, and also deposited with Cambridge Crystallographic Data Center (CCDC, University Chemical Laboratory, Lensfield Road, Cambridge CB21EW, U.K).

Acknowledgment. This work was supported by grants from the Japan Society for Promotion of Science (RFTF 97P00302).

Supporting Information Available: Synthetic procedures and/or spectral data of **4** (*n* = 6−12,16) and **7**−**15**; tables of atomic coordinates, bond lengths, and angles. The material is found in libraries on microfiche. This material is available free of charge via the Internet at http://pubs.acs.org.

JA983907U