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Optical Resolution of Chiral Buckybowls by Chiral HPLC

Ryoji Tsuruoka,[1] Shuhei Higashibayashi,[1] Takeharu Ishikawa,[2] Shinji Toyota,[2] and Hidehiro Sakurai*[1,3]
[1]*Research Center for Molecular Scale Nanoscience, Institute for Molecular Science, Myodaiji, Okazaki 444-8787*
[2]*Department of Chemistry, Faculty of Science, Okayama University of Science, 1-1 Ridaicho, Kita-ku, Okayama 700-0005*
[3]*PRESTO, Japan Science and Technology Agency, Tokyo 102-0075*

(Received April 5, 2010; CL-100331; E-mail: hsakurai@ims.ac.jp)

Optical resolution of chiral buckybowls, C_3 symmetric trimethylsumanene derivatives, was achieved by chiral HPLC. Enantiomeric excess (ee) of enatioselectively prepared trimethyltris(trimethylsilyl)sumanene was determined by the chiral HPLC analysis. The enantiomers of racemic trimethylsumanenetrione were separated, and the bowl inversion energy barrier was determined by the CD spectra.

Buckybowls have been a focus of recent attention because of their interesting physical properties derived from the bowl-shaped π-conjugated aromatic structure.[1] One of the interesting features of the structure is the chirality of these spherical aromatic compounds unlike planer ones, named *Bowl chirality*. The bowl chirality is expected to provide fascinating characters for their applicability not only for asymmetric molecular recognition and chiral ligands for transition metals but also for precursors of chiral fullerenes and carbon nanotubes in chemical synthesis. Enantiopure or -enriched chiral buckybowls could be obtained by either asymmetric synthesis or optical resolution of racemate.[2] As an example of the former, we have recently achieved the first enantioselective synthesis of chiral trimethylsumanene (**1**) (Figure 1) by converting chirality based on sp^3 carbon to bowl chirality.[4] In contrast, the latter approach has not been reported, although those of related chiral fullerenes and carbon nanotubes have been reported.[5] We focus on optical resolution of chiral buckybowls, trimethyltris(trimethylsilyl)-sumanene (**2**)[4,6] and trimethylsumanenetrione (**3**) (Figure 1), by chiral HPLC, and determination of bowl inversion energy barrier of **3** by CD spectra.

Optical resolution of racemic trimethyltris(trimethylsilyl)-sumanene (**2**) was initially investigated for the following reasons. First, C_3 symmetric tris(trimethylsilyl)sumanene derivative **2** is not racemized because of the presence of stereogenic centers at the sp^3 carbons at the benzilic positions. Second, they are ideal derivatives of enantioselectively prepared C_3 symmetric substituted sumanenes owing to easy preparation and derivatization as well as the storable stability without racemization. The ee of enantioselectively prepared substituted sumanenes would be easily determined by the chiral HPLC analysis of the tris(trimethylsilyl) derivatives as well. Chiral column DAICEL CHIRALPAK® IA, which is composed of amylose tris(3,5-dimethylphenylcarbamate), realized the desired optical resolution. Although it was difficult to separate the enantiomers of **2** under common eluent conditions such as a mixture of hexane and 2-propanol, they can be resolved by using 2-propanol as sole eluent (Figure 2) to afford each enantiomer of **2**. Under the optimized conditions, the ee of enantioselectively prepared (*C*)-**2**[3] was also determined to be 89% ee, which agrees with the value of (*C*)-**1** previously determined by using chiral derivatizing reagent (90% ee, Scheme 1).[4]

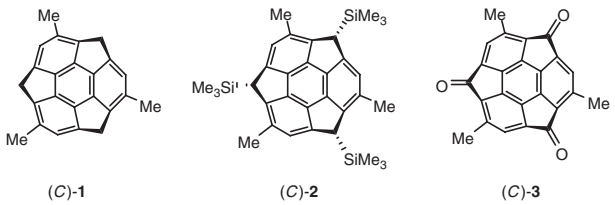


Figure 1. Structures of (*C*)-8,13,18-trimethylsumanene (**1**), (*C*)-(8*R*,13*R*,18*R*)-10,15,20-trimethyl-8,13,18-tris(trimethylsilyl)-sumanene (**2**), and (*C*)-10,15,20-trimethylsumanene-8,13,18-trione (**3**).[3]

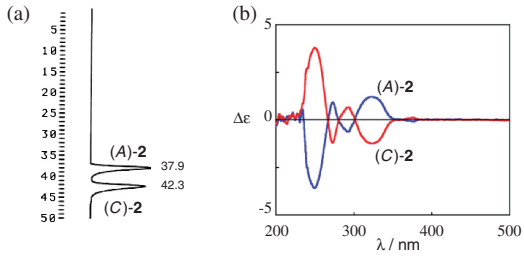
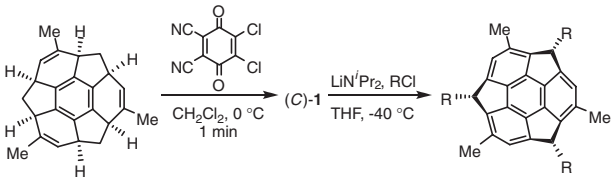


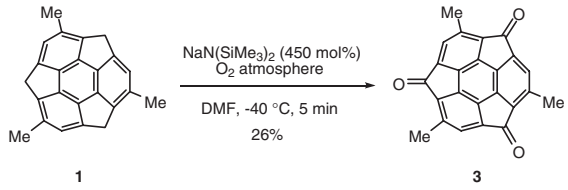
Figure 2. (a) Optical resolution of **2** by chiral HPLC (DAICEL CHIRALPAK IA, 2-propanol, retention time (t_R); 38 min for (*A*)-**2**, 42 min for (*C*)-**2**). (b) CD spectra of each enantiomer in $CHCl_3$.



[a]Determined by HPLC. [b]Determined by ^{1}H NMR.

Scheme 1. Determination of ee of enantioselectively synthesized (*C*)-**1**.

Next, we investigated the optical resolution of racemic **3**. The racemization energy barrier of **3** was estimated to be ca. 23.5 kcal mol^{-1},[7] which corresponds to ca. 44 h half-life at 10 °C. This could be sufficiently high to obtain enantioenriched **3** in HPLC time scale. Racemic **3** was prepared by aerobic oxidation of racemic **1** (Scheme 2). Reaction of **1** with sodium hexamethyldisilazide and molecular oxygen in DMF at low temperature for 5 min gave the desired product in 26% yield.[8] As expected, optical resolution of **3** was attained at 9 °C and afforded each enantioenriched sample of **3** (Figure 3). Absolute configuration of each enantiomer was assigned as (*A*)-**3** (t_R =



Scheme 2. Synthesis of trimethylsumanenetrione (**3**).

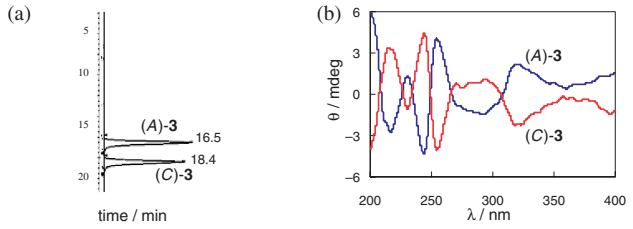


Figure 3. (a) Optical resolution of **3** by chiral HPLC (DAICEL CHIRALPAK IA, hexane/2-propanol = 60/40, 9 °C, retention time (t_R); 17 min for (*A*)-**3**, 18 min for (*C*)-**3**). (b) CD spectra of enantioenriched **3** in CH_3CN at 27 °C.

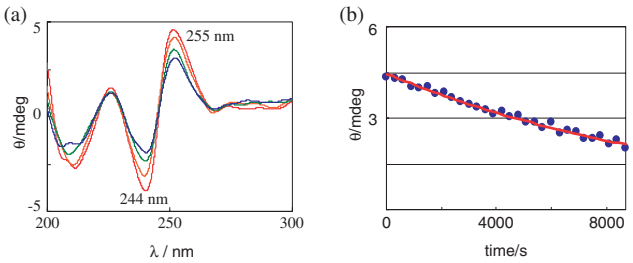


Figure 4. (a) Time-dependent decay of intensity of CD spectra of (*A*)-**3** in CH_3CN at 30 °C (red: 0 h, orange: 1 h, green: 2 h, blue: 3 h). (b) Decay of ellipse θ and their fitting curve at 255 nm in CH_3CN at 30 °C.

17 min) and (*C*)-**3** (t_R = 18 min) by the fact that enantioenriched sample prepared from (*C*)-**1** possessed t_R = 18 min.[9]

With enantioenriched **3** in hand by chiral HPLC separation, the bowl inversion energy barrier of **3** can be determined by CD spectra measurement.[4] Bowl inversion is a characteristic feature of buckybowls and has been extensively studied by experimental and theoretical methods.[10,11] A limitation of commonly used NMR methods for experimental determination of the energies is that those of buckybowls without diastereotopic protons cannot be determined by the technique.[10] In contrast, the energies of enantiopure or -enriched chiral buckybowls even without diastereotopic protons such as **3** can be determined by CD spectra measurement because they are racemized through bowl inversion. By time-dependent decay of the intensity of CD spectra of **3** at 255 nm at 30 °C (Figure 4), the energy barrier was determined to be 23.4 and 23.3 kcal mol^{-1} in CH_3CN and CH_2Cl_2, respectively.[9] These experimental values showed good agreement with predicted values.[7]

As described above, we have succeeded in the first optical resolution of chiral buckybowls, C_3 symmetric sumanene derivatives **2** and **3**, by chiral HPLC. Chiral HPLC analysis also enabled us to determine the ee of enantioselectively prepared **2**. With thus-obtained enantioenriched **3**, the bowl inversion barrier energy was determined by the CD spectra measurement. CD spectra is a powerful method to determine bowl inversion barrier energy to elucidate the structure–energy correlation.

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7 The energy barrier of **3** was estimated by comparison between calculated values (sumanene: 18.3, **1**: 19.3, and **3**: 21.5 kcal mol^{-1}, B3LYP/6-311+G**) and experimental values (sumanene: 19.7–20.4 and **1**: 21.6 kcal mol^{-1}).

8 Longer reaction time (2 h) gave lower yield (16%) possibly owing to overreactions.

9 See Supporting Information.

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