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Stereogenic Motif Consisting of Rigid Ring and Intraannular Chains: Isolation and Structures of Stereoisomers of 9-Alkyl-1,8-anthrylene−Butadiynylene Cyclic Dimers[1]

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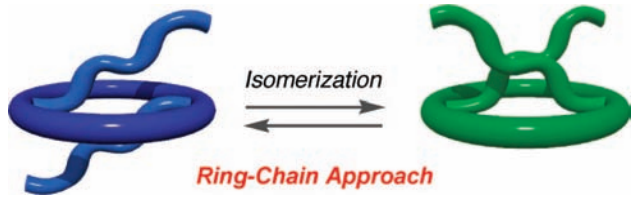
ABSTRACT



Stereoisomers of the title π-conjugated compounds with intraannular propyl and butyl groups were isolated by chromatography. The high barrier to isomerization is attributed to the steric hindrance between the alkyl chains and the rigid framework.

Arylene−ethynylene oligomers have attracted attention as novel π-conjugated compounds, especially in the fields of structural, supramolecular, and functional molecular chemistry.[2] We have synthesized various oligomers having anthracene units as arene moieties to create a new type of π system.[3] Those studies revealed that the structures and properties of cyclic anthrylene oligomers with acetylene and diacetylene linkers were significantly influenced by the numbers of building units and connection sites of anthracene moieties depending on the geometrical requirements. We recently succeeded in the synthesis of the smallest cyclic oligomer, 1,8-anthrylene−ethynylene cyclic dimer **1** (Figure 1).[4] X-ray analysis revealed that this cyclic structure is rigid and planar regardless of the steric hindrance between hydrogen atoms oriented toward the central ring. In contrast, the cyclic structure of monoanthraquinone analogue **2** is no longer planar to avoid congestion with the carbonyl oxygen atom.

These compounds inspired us to utilize the rigid ring system in the design of a new type of stereoisomers based on steric interactions with intraannular substituents, which

(1) Part 11 of "Chemistry of Anthracene-Acetylene Oligomers." For part 10, see: (a) Toyota, S.; Miyahara, H.; Goichi, M.; Wakamatsu, K.; Iwanaga, T. *Bull. Chem. Soc. Jpn.* **2008**, *81*, 1147.

(2) (a) Sadowy, A. L.; Tykwinski, R. R. *Modern Supramolecular Chemistry*; Diederich, F., Stang, P. J., Tykwinski, R. R., Eds.; Wiley-VCH: Weinheim, 2008; Chapter 6. (b) Zhang, W.; Moore, J. S. *Angew. Chem., Int. Ed.* **2006**, *45*, 4416. (c) Spitler, E. L.; Johnson II, C. A.; Haley, M. M. *Chem. Rev.* **2006**, *106*, 5344. (d) Khan, A.; Kaiser, C.; Hecht, S. *Angew. Chem., Int. Ed.* **2006**, *45*, 1878. (e) Marsden, J. A.; Palmer, G. J.; Haley, M. M. *Eur. J. Org. Chem.* **2003**, 2355. (f) Zhao, D.; Moore, J. S. *Chem. Commun.* **2003**, 807.

(3) (a) Toyota, S.; Goichi, M.; Kotani, M. *Angew. Chem., Int. Ed.* **2004**, *43*, 2248. (b) Goichi, M.; Miyahara, H.; Toyota, S. *Chem. Lett.* **2006**, *35*, 920. (c) Goichi, M.; Yamasaki, S.; Miyahara, H.; Wakamatsu, K.; Akashi, H.; Toyota, S. *Chem. Lett.* **2007**, *36*, 404. (d) Ishikawa, T.; Shimasaki, T.; Akashi, H.; Toyota, S. *Org. Lett.* **2008**, *10*, 417.

(4) Toyota, S.; Kurokawa, M.; Araki, M.; Nakamura, K.; Iwanaga, T. *Org. Lett.* **2007**, *9*, 3655.

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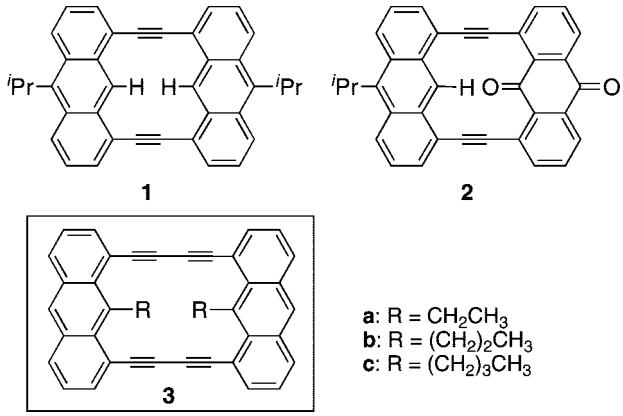
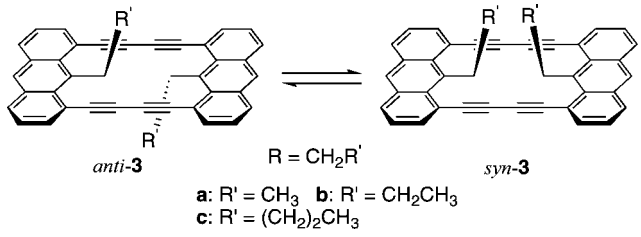


Figure 1. 1,8-Anthrylene cyclic dimers with acetylene and diacetylene linkers.

are known to play important roles in controlling the solubility and functions of shape-persistent phenylene−ethynylene macrocyclic oligomers.[2a,5] To generate stereoisomerism, we designed 9-alkyl-1,8-anthrylene−butadiynylene cyclic dimer **3**,[6] in which the central ring was enlarged by means of diacetylene linkers to accommodate two intraannular alkyl groups. For R = ethyl or longer alkyl groups, their tip moiety (R′ in Scheme 1) prefers to take a bisected conformation

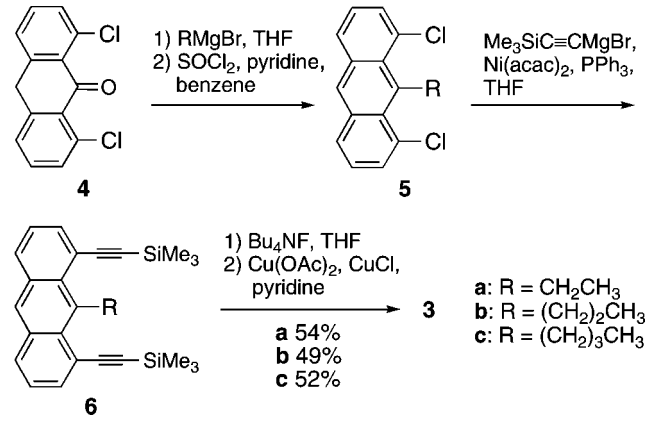
Scheme 1. Interconversion between *anti* and *syn* Isomers of **3**



relative to the averaged anthracene planes to avoid steric interactions with the macrocyclic moiety. Therefore, the two R′ moieties in each molecule can be found on the same side or opposite sides of the ring system, generating *syn* and *anti* forms, respectively. If isomerization between the two isomers due to motion of the alkyl groups is sufficiently retarded by steric hindrance, the isomers can be isolated at room temperature. We synthesized target compounds having different alkyl groups and successfully isolated the stereoisomers for R = propyl and butyl groups. The structural and spectroscopic data of these isomers as well as the substituent effect on the barrier to isomerization are discussed in terms of steric effects. We herein propose a novel ring-chain approach to the creation of a new type of stereoisomer.

The target compounds were prepared according to Scheme 2. 9-Alkyl-1,8-dichloroanthracenes **5** were prepared from **4**[7]

Scheme 2. Synthesis of Compounds **3**



by the Grignard reaction and dehydration with thionyl chloride in pyridine[8] in moderate to low yields. Two ethynyl groups were introduced into the anthracene moiety by Ni-catalyzed cross-coupling of **5** with the ethynyl Grignard reagent in good yields.[9] After desilylation of **6** with TBAF, the Eglinton coupling of the terminal alkynes was carried out with Cu reagents in pyridine.[10] The desired compounds were obtained in ca. 50% yields as stable red-orange solids. In the ^{1}H NMR spectra of **3b** and **3c**, two sets of alkyl signals appeared in ca. 1:1 ratio at room temperature, indicating the presence of diastereomers, and these were separated by chromatography. The less and more polar isomers of **3c** were unambiguously assigned to the *anti* and *syn*, respectively, as revealed by the X-ray analysis discussed below. The isomers of **3b** are similarly assigned by spectroscopic data and physical properties.[11] In contrast, the alkyl signals were broad at room temperature in the ^{1}H NMR spectrum of **3a** and were separated into two sets in 55:45 ratio at −40 °C (Figure 2). We consider that the major isomer is assigned to *syn* on the basis of the chemical shifts of the corresponding methylene signals in the isomers of **3b** and **3c**. The results indicate that the isomerization of **3a** is much faster than the laboratory time scale.

(5) For example, Höger, S.; Weber, J.; Leppert, A.; Enkelmann, V. *Beilstein J. Org. Chem.* **2008**, *4*, 1. (b) Fischer, M.; Höger, S. *Tetrahedron* **2003**, *59*, 9441.

(6) (a) The parent compound of this framework is known. Akiyama, S.; Misumi, S.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1960**, *33*, 1293. (b) This system was recently applied to organic phototransistors. Zhao, W.; Tang, Q.; Chan, H. S.; Xu, J.; Lo, K. Y.; Miao, Q. *Chem. Commun.* **2008**, 4324.

(7) House, H. O.; Hrabie, J. A.; VanDerveer, D. *J. Org. Chem.* **1986**, *51*, 921.

(8) Oki, M.; Matsusue, M.; Akinaga, T.; Matsumoto, Y.; Toyota, S. *Bull. Chem. Soc. Jpn.* **1994**, *67*, 2831. When the 9-anthrols were treated with P_2O_5 for dehydration, the reaction product was contaminated by a large amount of 9-alkylidene isomers.

(9) Katz, H. E. *J. Org. Chem.* **1989**, *54*, 2179.

(10) Simemsen, P.; Livingston, R. C.; Diederich, F. *Angew. Chem., Int. Ed.* **2000**, *39*, 2632. The macrocyclization was carried out at ca. 4×10^{-3} mol/L. The yield was not significantly affected by the concentration so much as long as the organic reactant was dissolved in the solvent.

(11) X-ray data of *syn*-**3b** are given in Supporting Information. As for **3b** and **3c**, the less polar nature of the *anti* forms is attributed to their centrosymmetric structure leading to zero or a negligibly small value of the dipole moment, while the *syn* forms are noncentrosymmetric.

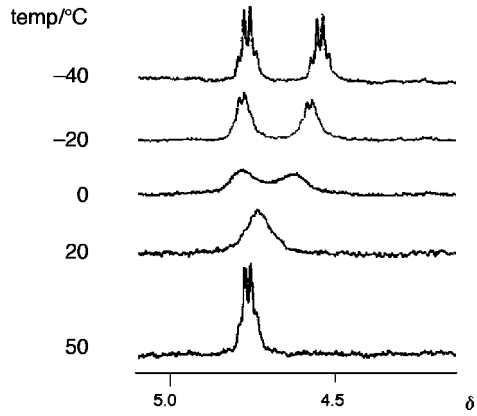


Figure 2. Variable-temperature ^{1}H NMR spectra of signals due to ethyl-methylene protons of **3a** in $CDCl_3$.

The X-ray structures of *anti*-**3c** and *syn*-**3c** are shown in Figure 3,[12] where the relative orientation of the two butyl groups is apparently different. The sp carbons are slightly deformed (bond angles 173−179°) to the outside of the central ring, forming slightly curved linkers. In each anthracene unit, out-of-plane deformations are notable around the peri substituents. In particular, C(9) atom is oriented away from the averaged aromatic plane while keeping the planarity at the carbon atom. Folding angles are 24−26° and are comparable to those of other noncyclic 1,8,9-trisubstituted anthracenes.[13] The macrocyclic framework of the *anti* and *syn* isomers is weakly deformed from the perfect plane into a zigzag and a bow shape, respectively. These deformations allow molecules to avoid excessive steric congestion in the intraannular region. In the crystal packing of *anti*-**3c**, the anthracene moiety of one molecule is stacked with that of another molecule continuously (ca. 3.3 Å) to form a linear molecular network along the *c* axis (Figure 4). We consider that this packing is responsible for the low solubility of the *anti* form.

The structures of the *anti* and *syn* isomers of **3a**−**c** were optimized at the B3LYP/6-31G(d) level (Supporting Information). For **3c**, the X-ray structures were well reproduced by the structural optimization. The structural features of ethyl and propyl compounds are common to those of butyl compounds involving the deformation of framework moieties. The two isomers of **3a** have comparable energies,

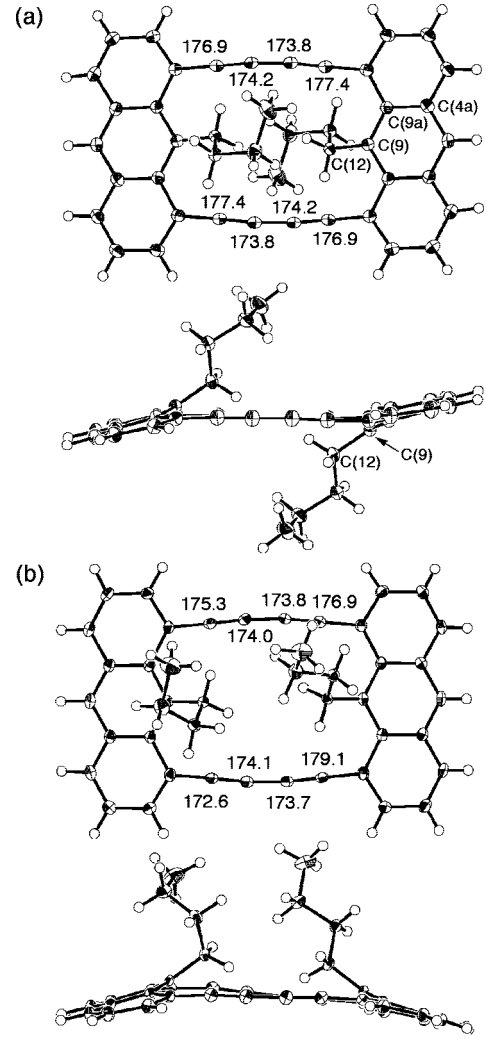


Figure 3. Top and side views of X-ray structures of (a) *anti*-**3c** and (b) *syn*-**3c** with thermal ellipsoids at 50% probabilities. Bond angles (deg) are indicated at sp carbons.

consistent with the experimental ratio. In contrast, the *anti* isomers are more stable by 4 kJ/mol than the *syn* isomers for **3b** and **3c**.

Compounds **3a**−**c** showed intense and structured bands in the range of 400−500 nm peaking at 492 nm in the UV−vis spectra measured in $CHCl_3$. The introduction of alkyl groups resulted in a bathochromic shift of ca. 30 nm compared with that of parent compound **3** (R = H) (465 nm).[6] Fluorescence spectra gave intense emission bands at ca. 504 nm (Φ_f 0.32−0.43) for all of the compounds. These results indicate that the electronic properties are little influenced by the kind of alkyl group and the stereochemistry.

The rate of isomerization was estimated by variable-temperature ^{1}H NMR measurements of **3a** (Figure 2). Ethyl-methylene signals of the two isomers ($\Delta\nu$ 75 Hz) coalesced at ca. 5 °C, corresponding to a barrier to isomerization of 56 kJ/mol. The kinetic data of the other compounds were determined by classical kinetics. The isomerization of *anti*-**3b** took place slowly at 100 °C in toluene-d_8, and quantitative

(12) **X-ray Data.** *anti*-**3c**: formula $C_{44}H_{32}$, FW = 560.70, triclinic, space group *P*1 (No. 2), *a* = 9.0642(7), *b* = 10.2306(7), *c* = 10.1873(7) Å, α = 113.734(5), *β* = 100.374(3), *γ* = 111.086(2)°, *V* = 746.24(9) Å^3, *Z* = 1, D_c = 1.248 g/cm^3, μ(Mo Kα) = 0.070 mm^{-1}, *T* = 173 K, 2819 independent reflections, *R*1 = 0.0617, w*R*2 = 0.1673, GOF = 1.07, CCDC 705746. *syn*-**3c**: formula $C_{44}H_{32}$, FW = 560.70, triclinic, space group *P*1̄ (No. 2), *a* = 11.1772(7), *b* = 11.9076(14), *c* = 13.265(3) Å, α = 72.870(12), *β* = 72.915(14), *γ* = 68.027(9)°, *V* = 1530.6(4) Å^3, *Z* = 2, D_c = 1.217 g/cm^3, μ(Mo Kα) = 0.069 mm^{-1}, *T* = 113 K, 6933 independent reflections, *R*1 = 0.0586, w*R*2 = 0.1035, GOF = 0.95, CCDC 705747.

(13) The extent of folding is evaluated from the torsion angles of the C(4a)−C(9a)−C(9)−C(12) chain (see Figure 3a) and other corresponding sites. For example, the folding angles are 25° and 30° for 1,8-dichloro-9-methyl- and 1,8,9-tribromo-anthracenes. (a) Delleca, R. J.; Penfold, B. R.; Robinson, W. T. *Acta Crystallogr., Sect. B: Struct. Sci.* **1980**, *25B*, 1589. (b) Akiba, K.; Yamashita, M.; Yamamoto, Y.; Nagase, S. *J. Am. Chem. Soc.* **1999**, *121*, 10644.

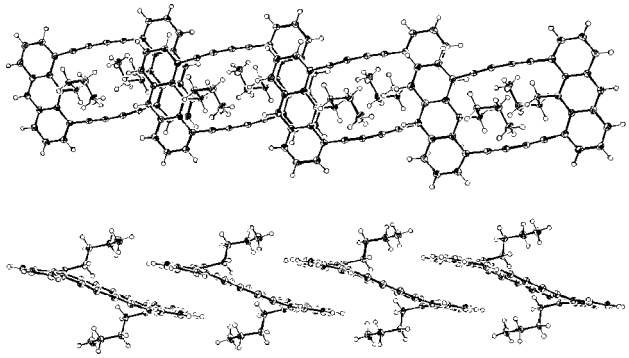


Figure 4. Two views of molecular stacking in packing diagram of *anti*-**3c**.

analysis of the course of isomerization gave the barrier to isomerization of 122 kJ/mol at 100 °C. No isomerization was observed for **3c** even though the sample was heated at 110 °C for 18 h in toluene-d_8:[14] the estimated lower limit of the barrier was 146 kJ/mol. These kinetic data demonstrate that the barriers to isomerization are enhanced in the order of ethyl, propyl, and butyl compounds. The isomerization requires threading of the tip of one of the alkyl chains into the rigid 18-membered ring via rotation of the C(9)−CH_2 bond. Hence, the long alkyl groups considerably destabilize the transition state of the isomerization.

In summary, we successfully isolated the stereoisomers of 1,8-anthrylene cyclic dimers with diacetylene linkers and intraannular alkyl substituents and showed a new stereogenic motif consisting of a rigid ring and two chains. It should be noted that the alkyl groups are conformationally locked for butyl compound **3c** under conventional conditions. We are developing this molecular design further for future structural modifications involving the introduction of bulkier alkyl groups or the use of shorter linkers and the formation of chiral structures.

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Supporting Information Available: Experimental procedures, compound characterization data, ^{1}H NMR, ^{13}C NMR, electronic spectra, calculated structures, and X-ray data of *anti*-**3c**, *syn*-**3c**, and *syn*-**3b** in CIF format. This material is available free of charge via the Internet at http://pubs.acs.org.

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(14) Sample of **3c** was significantly decomposed by heating for a longer time or at higher temperature.