

One-pot Synthesis of a Cyclic Pyrene Octamer from Two Bifunctionalized Pyrene Monomers

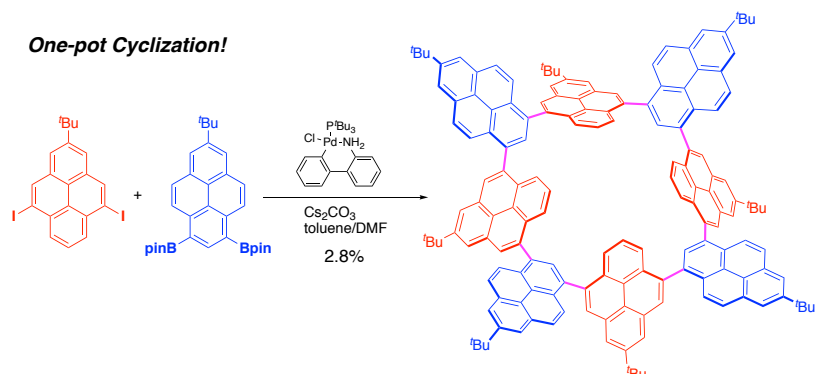
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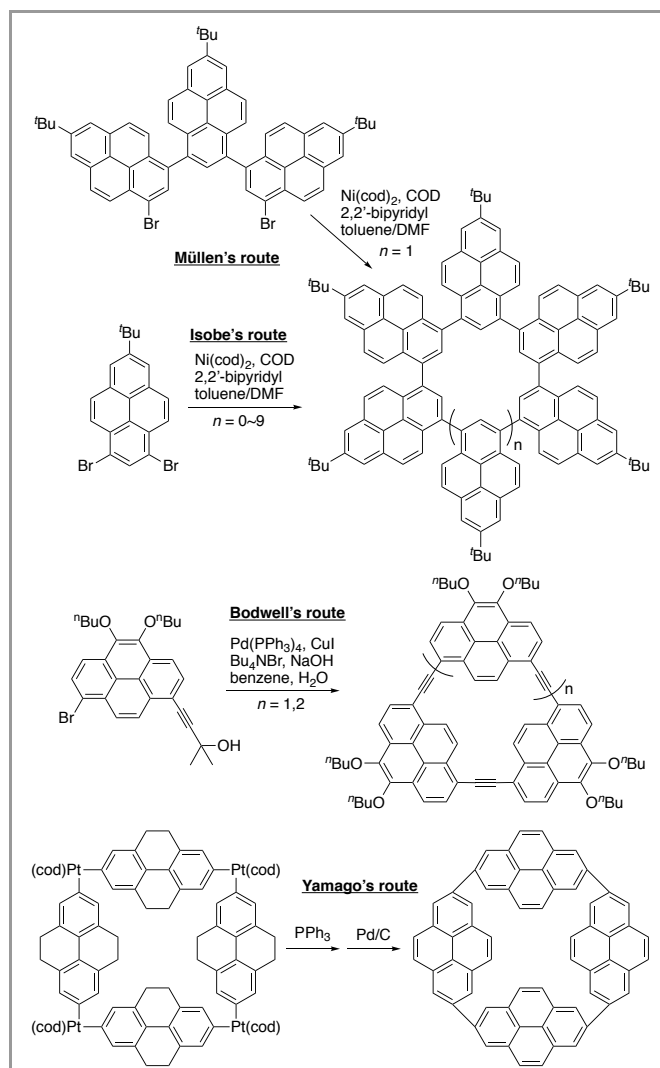
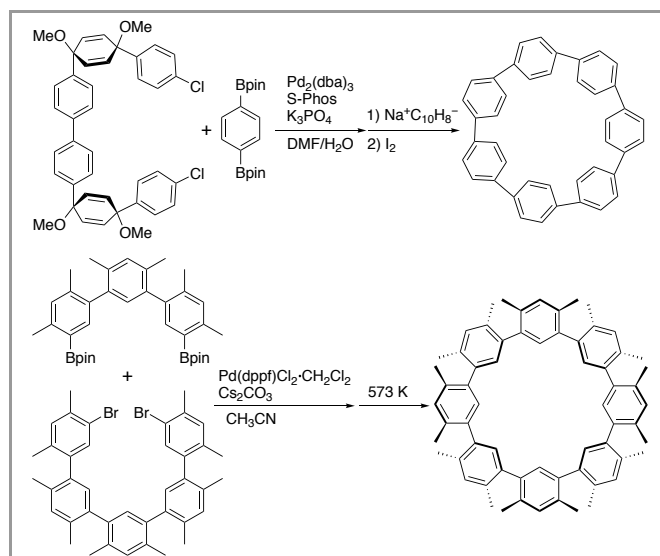
Abstract A 2,2'-*tert*-butyl-5,9-6',8'-cyclo-octameric pyrenylene ([8]CP) was synthesized by the one-pot Suzuki-Miyaura cross-coupling reaction from two kinds of bifunctionalized monomers as a rare example of cyclic octamer. The octameric molecular structure of [8]CP was revealed by single-crystal X-ray diffraction analysis.

Key words macrocycles, pyrene, cross-coupling, X-ray structure, octamer

Cycloarylenes have attracted much attention due to their unique structure, remarkable characteristics and potential applications in materials science.¹ As the building block of the cycloarylenes, a benzene ring is commonly used.²⁻⁴ There are not many examples of cycloarylenes based on polycyclic aromatic hydrocarbons (PAHs) that are larger than the benzene ring due to the rapidly increasing difficulty of synthesis. The structure of such macrocyclic compound is often an equilateral triangle⁵ or a regular hexagon⁶ except for cycloparaphenylenes (CPPs),⁴ due to the hexagon shape of the benzene ring.

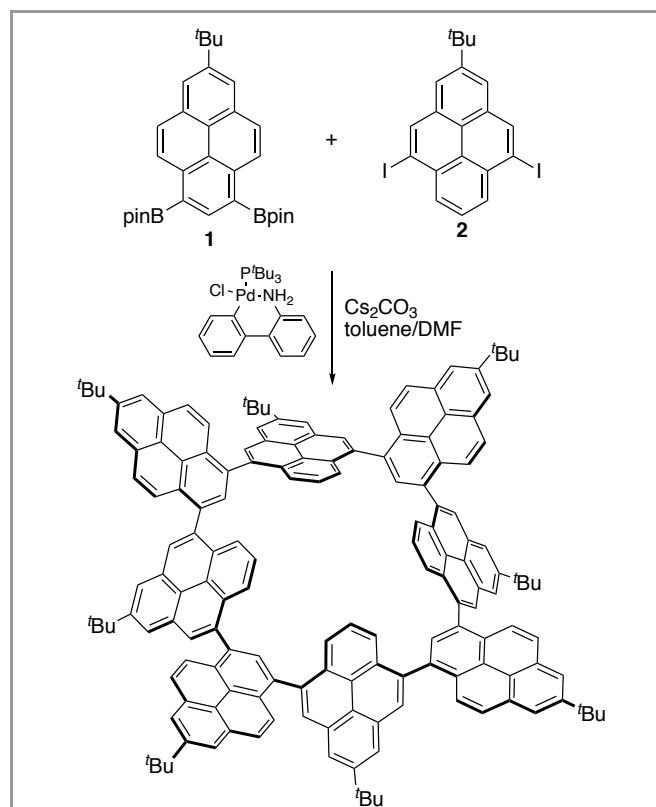
Pyrene is an important PAH among those building units for larger cycloarylenes because of its highly emissive property and large π -surface.⁷ The synthesis of cyclic pyrene oligomers has been challenging, which has led to the exploring of many synthetic strategies. In previous works, Müllen's group reported the stepwise synthesis of [6]cyclo-1,3-pyrenylene,⁸ and Isobe's group independently performed a one-pot nickel-mediated homo-coupling of 1,3-dibromopyrene⁹ (Scheme 1). Bodwell's group synthesized the [3] and [4]cyclo-1,8-pyrenylene-ethynylene by the self Sonogashira-coupling reaction.¹⁰ Yamago and coworkers synthesized [4]cyclo-2,7-pyrenylene by their platinum-mediated assembly method.¹¹ The reason for the formation of the tetramer in this case is that the platinum complex intermediate has a bonding angle of approximately 90°. These single-substrate reactions¹² worked well to give cyclic

pyrene oligomers¹³ and effectively shorten the reaction route, but the cross-coupling reaction with multiple substrates is also a powerful technique,¹⁴ especially when we want to selectively synthesize heptameric¹⁵ and octameric¹⁶ compounds (Scheme 2).

Scheme 1. Synthesis of various cyclo-pyrenylenes.⁸⁻¹¹Scheme 2. Synthesis of [7]CPP¹⁵ and [8]cyclo-*meta*-phenylene¹⁶ based on [6 + 1] and [3 + 5] Suzuki-Miyaura cross-coupling reactions, respectively.

Here, we report the synthesis of a 2,2'-*tert*-butyl-5,9-6',8'-cyclo-octameric pyrenylene ([8]CP) by the Suzuki-Miyaura

cross-coupling *via* a one-pot reaction between diiodopyrene and bis-borylated pyrene in an acceptable yield (Scheme 3).



Scheme 3. One-pot synthesis of octameric cyclopyrenylene [8]CP.

To prepare 6,8-diborylated pyrene **1**, *tert*-butyl group was introduced at the 2-position of pyrene to block the 1,3-positions followed by the bromination then borylation.¹⁷ This compound serves as a versatile platform in the synthesis of disubstituted pyrenes. Slow vapor diffusion of methanol into a chloroform solution of **1** afforded crystals suitable for X-ray diffraction analysis. 2-*tert*-Butyl-5,9-diodopyrene (**2**) was obtained through an indirect synthetic route reported by Müllen and coworkers.¹⁸

The [8]CP was synthesized by the Suzuki-Miyaura cross coupling reaction of **1** and **2** with palladium catalyst and cesium carbonate in a mixture of toluene and DMF as a cosolvent (Scheme 3). When all the substrates and reagents were mixed and heated at 100°C for 23 h, no target product was detected, but when the mixture was stirred at room temperature for 8 h and then heated for 16 h, the mass spectrometry showed that the target product was formed. This reaction was confirmed to be reproducible. The matrix-assisted-laser-desorption/ionization time-of-flight mass spectrometry (MALDI-TOF-MS) of the reaction mixture indicates the formation of oligomers up to nonamer (Figure S3). After purification by chromatography on silica gel with CH_2Cl_2 as the eluent and gel-permeation chromatography (GPC), among the products, the octameric oligomer [8]CP was isolated in 2.8% yield as a cyclic product. Isolated hexamer was confirmed as an acyclic molecule by HR-mass spectrometry (Figure S4). The coupling between the peri-positions would limit the steric angle. Therefore, the octamer with a reasonable ring size could be cyclized, giving in the selective octameric cyclization product which is unusual as a one-

pot synthesis. Totally eight equivalent carbon-carbon bonds were formed by this cross-coupling, which means that the reaction yield per one bond is going on at 64%. The compound has been characterized by ^1H NMR spectroscopy and high-resolution (HR) MALDI-TOF mass spectrometry. HR MALDI-TOF-MS detected a parent ion peak at $m/z = 2049.0026$ (calcd. for $\text{C}_{160}\text{H}_{128} = 2049.0011$ [M] $^+$) for **[8]CP** (Figure S2). The ^1H NMR spectrum of **[8]CP** in 1,1,2,2-tetrachloroethane- d_2 reveals two sets of signals that consists of four singlet peaks at 8.36, 8.34, 8.26 and 8.08 ppm, three doublet peaks at 8.10, 8.04 and 7.72 ppm, and one triplet peak at 7.61 ppm for aromatic protons, indicating the highly symmetric cyclic structure in solution (Figure S1).

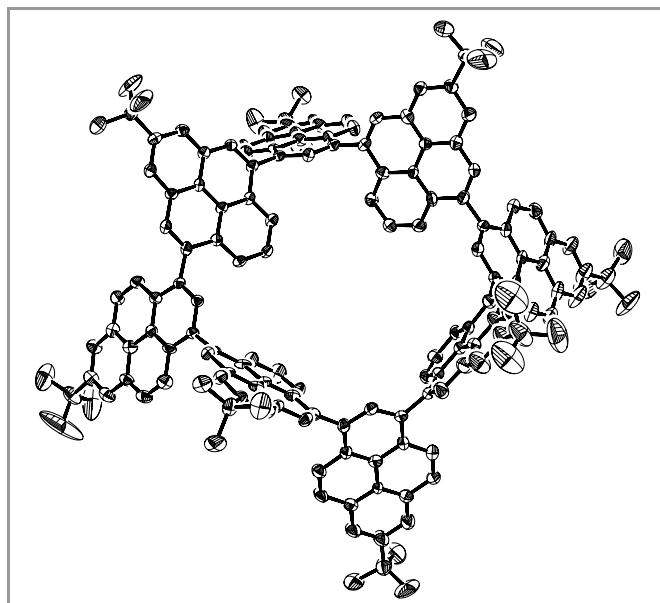


Figure 1 ORTEP diagram of single crystal X-ray structure of **[8]CP**. The ellipsoids are scaled at 50% probability. Hydrogen atoms are omitted for clarity.

The cyclic structure of **[8]CP** was finally determined by single crystal X-ray diffraction analysis (Figure 1). Slow vapor diffusion of methanol into a chloroform solution of **[8]CP** afforded crystals suitable for X-ray diffraction analysis. The macrocyclic structure is deformed in the crystal because two **[8]CP** molecules are nested and π -stacked. In the solid state, the dihedral angles between pyrene units are 72.5 – 88.4° , expecting that the small π -conjugation between pyrene units. To the best of our knowledge, this is the largest pyrene oligomer for which a single crystal structure has been obtained.

In summary, 2,2'-*tert*-butyl-5,9-6',8'-cyclo-octameric pyrenylene **[8]CP** was synthesized by the one-pot Suzuki-Miyaura cross coupling reaction from two kinds of monomers. The octameric molecular structure was revealed by X-ray diffraction analysis. Recently, we presented pyrene-based homoditopic molecular host, which has back-to-back arranged binding cavities.¹⁹ Taking advantage of the unique structural feature, **[8]CP** also can bind the spherical fullerenes owing to concave-convex complementarity. The directly-linked pyrene octamer would demonstrate a new potential of the planar cyclic pyrene oligomers. Examination of the photophysical properties of these complexes are active in progress.

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^1H NMR (500 MHz) spectra were recorded with a JEOL JNM-ECX500 spectrometer by using tetramethylsilane as an internal standard. High-resolution mass spectra (HRMS) were measured using the matrix-assisted laser desorption/ionization-time-of-flight (MALDI-TOF) method on a JEOL SpiralTOF/JMS-S3000 spectrometer. The diffraction data for compound **1** were collected at 100 K using a Rigaku VariMaxRAPID/a imaging plate diffractometer with graphite-monochromated Mo- $K\alpha$ radiation. X-ray crystallographic data for **[8]CP** were recorded at 90 K using a BRUKER-APEXII X-Ray diffractometer using Mo- $K\alpha$ radiation equipped with a large area CCD detector. TLC and gravity column chromatography were performed on Art. 5554 (Merck KGaA) plates and silica gel 60N (Kanto Chemical), respectively. Gel permeation chromatography (GPC) was performed on JAI LC-9225 eluted with chloroform. All solvents and chemicals were reagent-grade quality, obtained commercially and used without further purification. For spectral measurements, spectral-grade toluene was purchased from Nacalai Tesque.

2,2'-*tert*-Butyl-5,9-6',8'-cyclo-octameric pyrenylene (**[8]CP**)

Compound **1**¹⁷ (90 mg, 0.176 mmol), 2-*tert*-butyl-5,9-diiodopyrene (**2**)¹⁸ (90 mg, 0.176 mmol), Cs_2CO_3 (288 mg, 0.882 mmol), dry toluene (3 mL) and dry DMF (1.2 mL) was added to a 25 mL Schlenk flask. After degas with three freeze-pump-thaw cycles, the Pd catalyst **3** (24 mg, 0.046 mmol) was quickly added. After degassing again, the solution was stirred at room temperature for 8 h and then 100°C for 16 h. After cooling, the mixture was extracted with dichloromethane and washed with water and brine. After being concentrated by a rotary evaporator, the mixture was roughly separated on a silica gel column (dichloromethane). Then, the product mixture was separated by GPC (two connected columns with exclusion limits of 20,000 g/mol and 5000 g/mol). After 8 recycling, the main fraction was separated, and the fraction was recycled two times in the same GPC set-up to remove all the linear oligomers and enhance the purity of the cyclic product. At last, **[8]CP** was obtained in 2.8% yield (2.5 mg).

^1H NMR (tetrachloroethane- d_2 , 400 MHz): $\delta = 8.36$ (s, 8H), 8.34 (s, 8H), 8.26 (s, 8H), 8.10 (d, $J = 9.6$ Hz, 8H), 8.08 (s, 4H), 8.04 (d, $J = 9.6$ Hz, 8H), 7.72 (d, $J = 7.6$ Hz, 8H), 7.61 (t, $J = 7.6$ Hz, 4H), 1.58 (s, 36H) and 1.57 (s, 36H).

HRMS (MALDI-TOF): m/z [M] $^+$ calcd for $\text{C}_{160}\text{H}_{128}$: 2049.0011; found: 2049.0026.

UV-vis (CHCl_3): λ_{max} [ϵ [10^4 $\text{M}^{-1}\text{cm}^{-1}$]] = 288 (2.13), 338 (1.38) and 350 (1.53) nm. FI (CHCl_3): λ_{max} ($\lambda_{\text{ex}} = 350$ nm) = 425 nm. M.p. > 300°C .

Single-crystal X-ray diagram: crystals of **1** were grown by slow diffusion of methanol into a solution of **1** in CHCl_3 to yield colorless prisms. $\text{C}_{32}\text{H}_{40}\text{B}_2\text{O}_4$, $M_w = 510.29$, monoclinic, space group $P2_1/c$ (#14), $a = 12.5307(2)$ Å, $b = 11.4360(2)$ Å, $c = 20.0676(4)$ Å, $\beta = 94.2991(7)^\circ$, $V = 2867.60(9)$ Å 3 , $Z = 4$, $d_{\text{calcd}} = 1.182$ g/cm 3 , $F(000) = 1096$, θ range 2.070 – 27.5° , R indices $R_1 = 0.0480$ ($I > 2\sigma$), $wR_2 = 0.1385$ (all data). GOF = 1.080. CCDC 2023859. Single-crystal X-ray diagram: crystals of **[8]CP** were grown by slow diffusion of methanol into a solution of **[8]CP** in CHCl_3 to yield colorless prisms. $\text{C}_{160}\text{H}_{128}$, $M_w = 2050.62$, triclinic, space group $P-1$ (#2), $a = 17.391(3)$ Å, $b = 19.361(3)$ Å, $c = 26.681(4)$ Å, $\alpha = 82.806(3)^\circ$, $\beta = 77.912(3)^\circ$, $\gamma = 72.488(2)^\circ$, $V = 8359(2)$ Å 3 , $Z = 2$, $d_{\text{calcd}} = 0.815$ g/cm 3 , $F(000) = 2176$, θ range 2.070 – 25.00° , R indices $R_1 = 0.0853$ ($I > 2\sigma$), $wR_2 = 0.1990$ (all data). GOF = 1.005. CCDC 2023860. The contributions to the scattering arising from the presence of disordered solvents in the crystal of **[8]CP** were removed by use of the utility SQUEEZE in the PLATON software package.²⁰

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Supporting Information

no

Primary Data

no

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