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Synthesis of substituted anthracenes, pentaphenes and trinaphthylenes via alkyne-cyclotrimerization reaction

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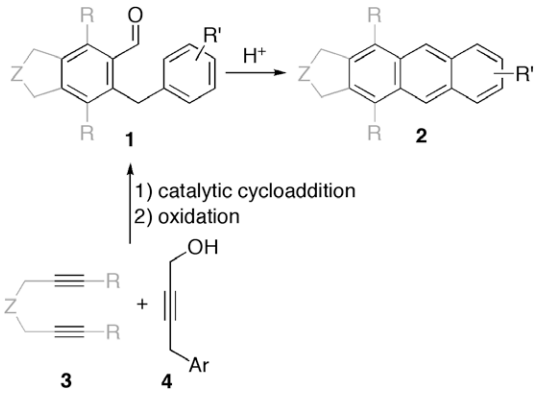
ABSTRACT

The [2+2+2] cycloaddition reaction of 1,6-diynes **3** with 4-aryl-2-butyn-1-ols **4** and the following oxidation of the resulting benzylic alcohols to the aldehydes **1** and then treatment with an acid catalyst provided annulated anthracenes **2** in good yields.

Anthracene and its derivatives are some of the most versatile polycyclic aromatic compounds. Thus, they have received wide utilities as a chromophor for sensors and markers in biological or supramolecular systems, a key species in the design of luminescent materials, a photochromic molecule by their photo-induced cycloaddition/cycloreversion and a core structure of organo-electronic materials.[1] Therefore, various methods for construction of anthracene framework have been developed, which include Friedel–Crafts reaction,[2] aromatic cyclodehydration,[3] Elbs reaction,[4] Bradsher-type reaction of diarylmethanes,[5] and [4+2] cycloaddition reactions with napthoquinones, quinodimethanes, radialenes, or benzynes.[6] In addition, several transition metal-mediated or -catalyzed cyclotrimerization processes have been reported for the rapid assembly of acenes: Ni- and Co-catalyzed or Zr-mediated alkyne-cyclotrimerization reactions via metallacycles derived from 1,2-dipropargylaromatic compounds and Pd-catalyzed benzyne cyclotrimerization.[7] These methodologies are useful for preparation of higher polycyclic aromatic hydrocarbons (PAHs) and also synthesis of acenes having a heteroaromatic substructure(s).

Based on our results of developing a highly practical procedure for synthesizing substituted benzenes by the [2+2+2] alkyne-cyclotrimerization which is catalyzed by a $CoCl_2{\cdot}6H_2O$/Zn reagent in the presence of an appropriate ligand,[8] we planned a two-step preparation of benzyl aldehydes **1**, which are the substrate of Bradsher-type cyclization/aromatization reaction, by the cycloaddition of diynes **3** and 4-aryl-2-butyn-1-ols **4** and the following oxidation (Scheme 1). We have shown that the propargyl alcohols **4** are good substrates for the selective cross-coupling with diynes **3**, owing to their coordination effect of the propargyl oxygen to the metal center in an active catalyst. Herein we report the results of the study for the three-step synthesis of substituted anthracenes **2** from alkyne starting materials, which were applied to synthesis of substituted pentaphenes and trinaphthylenes.



Scheme 1. Synthetic plan for anthracenes **2** from diynes **3** and benzyl alkynes **4**.

Synthesis of 4-aryl-2-butyn-1-ols **4** required for the synthesis was illustrated in Scheme 2. Compounds of type **4** were synthesized by the cobalt-catalyzed coupling reaction[9] of benzyl chlorides with trimethylsilylethynyl–magnesium bromide, developed by us, and the following protiodesilylation and hydroxymethylation reactions. Similarly, bis-propargyl alcohol **4c** was prepared from 1,3-di(chloromethyl)benzene in 51% overall yield.

With compounds **4a–c**, we carried out three-step synthesis of anthracenes **2** from diynes **3** and 4-aryl-2-butyn-1-ols **4** (Scheme 3). Thus, to a mixture of **3**, **4** (1.18 equiv) and Zn powder (10 mol %) in THF was added a solution of 2-(2,6-diisopropylimino)methylpyridine (Dipimp, 6 mol %) and $CoCl_2{\cdot}6H_2O$ (5 mol %) in THF at room temperature and the mixture was stirred at ambient temperature overnight. The mixture was filtered through a pad of Celite with ether. The resulting adducts **5** were converted to the corresponding aldehydes by treatment with PCC/Celite in

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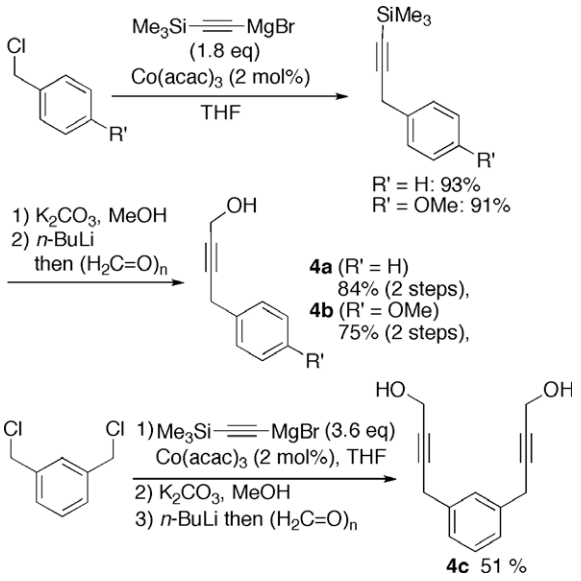
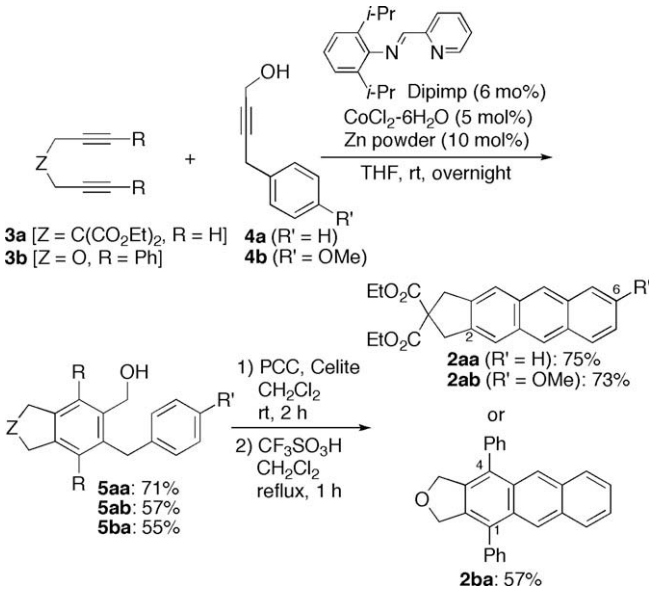


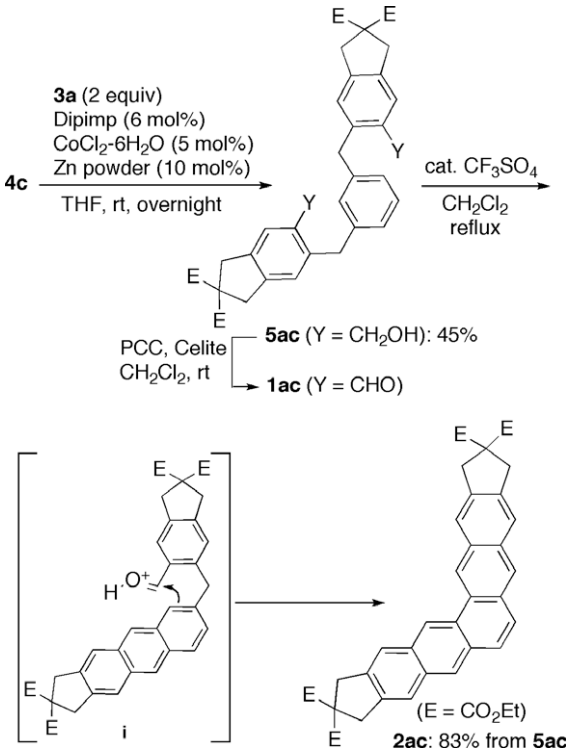
Scheme 2. Preparation of **4**.



Scheme 3. Three-step synthesis of anthracenes **2** from **3** and **4**.

CH_2Cl_2 at room temperature, which were successively treated with a catalytic amount of CF_3SO_3H in CH_2Cl_2 at reflux temperature for 1 h to provide the desired anthracenes **2** in good yields. Anthracenes having a carbocyclic as well as heterocyclic-saturated ring which was originated from tether structure of diynes **3** were obtained. Introduction of substitution(s) at the 1 and 4 positions of **2** as the case of **2ba** was readily carried out by use of the corresponding substituted diynes **3**. Substituent(s) at the 5–8 position(s) may be possible by using the corresponding **4** as exemplified by synthesis of **2ab**.

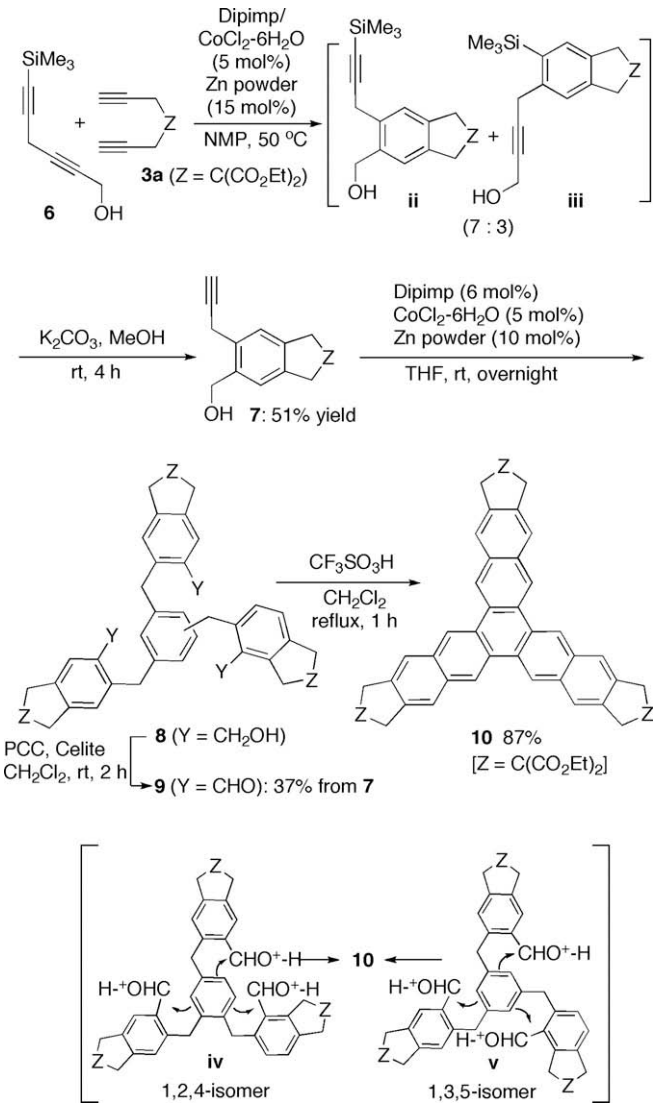
Scheme 4 shows an efficient synthesis of pentaphenes via a tandem cycloaddition reaction starting from dipropargylic compound **4c**. With the use of **4c** as a mono-alkyne counterpart, the cycloaddition of 1,6-diyne **3a** proceeded in a tandem fashion to yield bis-benzylic alcohol **5ac**. The sequential reactions of oxidation/acid-catalyzed cyclization converted the resulting



Scheme 4. Synthesis of pentaphene **2ac**.

5ac smoothly to bis-annulated pentaphene **2ac**. Cyclization/aromatization of dialdehyde **1ac** could proceed regioselectively through a possible intermediate **i**, illustrated in Scheme 4, to provide pentaphene **2ac** exclusively but not a pentacene derivative.[5j]

As shown in Scheme 5, cyclotrimerization approach enables synthesis of more complex molecules from simple alkyne starting materials. Thus, cyclotrimerization of 1-alkyne **7** followed by oxidation/acid-catalyzed cyclization provided substituted trinaphthylenes. *o*-Propargyl benzyl alcohol **7** could be synthesized by using cobalt-catalyzed alkyne cycloaddition reaction: the [2+2+2] cycloaddition reaction of 2,5-hexadiyne **6**[10] and 1,6-diyne **3a** catalyzed by Dipimp/$CoCl_2{\cdot}6H_2O$/Zn in NMP proceeded selectively to give a 7:3 mixture of adducts **ii** and **iii** and the following protiodesilylation of the mixture provided **7** in 51% overall yield. Although the compounds **ii** and **iii** were inseparable, treatment of the mixture with K_2CO_3/MeOH gave **7** and unchanged **iii**, which could be readily separated by silica gel column chromatography. The *o*-propargyl benzylic alcohol **7** thus prepared was again subjected to [2+2+2] cycloaddition catalysis: treatment of **7** with a Dipimp/$CoCl_2{\cdot}6H_2O$/Zn catalyst gave intermolecularly cyclotrimelized products **8** as a mixture of 1,3,5- and 1,2,4-regioisomers. After oxidation of the crude mixture of **8** to the corresponding tri-aldehyde **9** (37% yield from **7** through two steps), cyclization of **9** by treatment with trifluoroacetic acid in CH_2Cl_2 produced smoothly trinaphthylene **10** in 87% yield. To the best of our knowledge, this is the first example of the synthesis of trinaphthylenes via triple Bradsher cyclization reactions on a single benzene ring. It is noteworthy that high yield production of **10** from a regioisomeric mixture of trisubstituted benzene **9** indicated regioselective cyclizations of both 1,2,4- and 1,3,5-trisubstituted isomers through **iv** and **v** illustrated in Scheme 5. Thus, the compound **10** was effectively synthesized from non-aromatic substrates **6** and **3a** through five steps. Trinaphthylenes are analogues of triphenylenes, which are well-known



Scheme 5. Synthesis of trinaphthylene **10**.

for their remarkable self-assembling and charge-transporting properties,[11] and are a simplest member of star-shaped angularly fused oligoacenes (starphene).[12] The synthesis of these molecules is challenging.

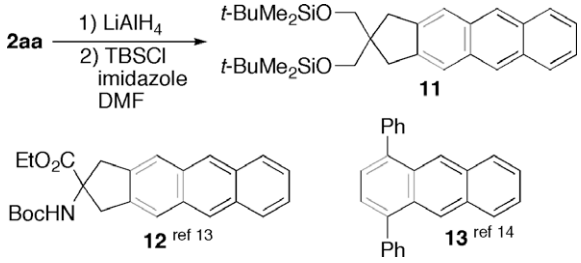
Table 1 shows absorption spectral data of the new annulated anthracene derivatives, that is, anthracenes **2aa**, **2ab**, **2ba**, pentaphene **2ac**, and trinaphthylene **10**, the annulated structures of which may cause a weak strain to aromatic ring(s). Comparing with data for anthracene, introduction of five-membered ring annulation onto anthracene, that is, in **2aa** and **11**, did not affect UV absorption so much as observed for the known compound **12**.[13] Similarly, between 1,4-diphenyl derivatives **2ba** and **13**[14] a large difference was not observed.

In summary, we have demonstrated that catalytic [2+2+2] cycloaddition reactions[15] of alkynes play an efficient role as a key reaction for construction of anthracene, penthaphene and trinaphthylene structures.[16] By taking advantage of the function of annulated substructure(s) and/or further substituent(s) on anthracene such as Ph groups in **2ba**, functionalization of these anthracenes might be expected. Study on utilization in this direction is underway.

Table 1
UV absorption of anthracenes **2aa**, **2ab**, **2ba**, pentaphene **2ac** and trinaphthylene **10**

Compound	λ_{abs}[a] (nm)
2aa	223, 260, 313, 328, 345, 362, 382
11[b]	262, 310, 324, 345, 362, 382
2ab	233, 259, 318, 335, 353, 374, 393
2ba	261, 353, 372, 392
2ac	236, 255, 264, 296, 322, 332, 354, 364, 403
10	247, 259, 292, 305, 319, 343, 374, 393
Anthracene	252, 295, 312, 326, 342, 359, 378
12[c]	312, 326, 342, 359, 378[13]
13[d]	260, 320, 337, 354, 371, 391[14]

[a] Unless otherwise indicated, UV absorption spectra were measured for a $CHCl_3$ solution (0.1 mM). Wavelength underlined are $\lambda_{abs\ max}$.
[b] See below.
[c] In EtOH (see Ref. 13). For structure, see below.
[d] In CH_2Cl_2 (see Ref. 14). For structure, see below.



Acknowledgment

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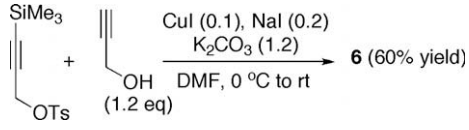

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16. ^{1}H NMR data of new anthracenes: **2aa**: ($CDCl_3$, 500 MHz) δ 8.32 (s, 2H), 7.96 (dd, J = 3.5, 6 Hz, 2H), 7.80 (s, 2H), 7.42 (dd, J = 2.5, 6 Hz, 2H), 4.22 (q, J = 7.0 Hz, 4H), 3.74 (s, 4H), 1.26 (t, J = 7.0 Hz, 6H). Compound **2ab**: ($CDCl_3$, 500 MHz) δ 8.24 (s, 1H), 8.17 (s, 1H), 7.85 (d, J = 9 Hz, 1H), 7.75 (s, 1H), 7.74 (s, 1H), 7.16 (d, J = 2.5 Hz, 1H), 7.12 (dd, J = 2.3, 9.3 Hz, 1H), 4.22 (q, J = 7.0 Hz, 4H), 3.96 (s, 3H), 3.73 (s, 4H), 1.26 (t, J = 7.0 Hz, 6H). Compound **2ba**: ($CDCl_3$, 500 MHz) δ 8.27 (s, 2H), 7.84 (dd, J = 3.0, 7.0 Hz, 2H), 7.48–7.53 (m, 10H), 7.38 (dd, J = 3.0, 6.5 Hz, 2H), 5.09 (s, 4H). Compound **2ac**: ($CDCl_3$, 500 MHz) δ 9.09 (s, 2H), 8.14 (s, 2H), 7.93 (s, 2H), 7.80 (s, 2H), 7.57 (s, 2H), 4.23 (q, J = 7.0 Hz, 8H), 3.80 (s, 4H), 3.78 (s, 4H), 1.28 (t, J = 7.0 Hz, 12H). Compound **10**: ($CDCl_3$, 600 MHz) δ 8.35 (s, 6H), 7.59 (s, 6H), 4.30 (q, J = 7.2 Hz, 12H), 3.80 (s, 12H), 1.33 (t, J = 7.2 Hz, 18H).