in 5 mL of CH$_2$Cl$_2$; after stirring for 12 h at rt, the solution was filtered, the filtrate was evaporated, and the residue was dissolved in 10 mL of DMF and added in the usual way to 100 mL of pyridine at 80 °C; after removal of the solvent in vacuo, the residue contained only traces of lactams.

Acknowledgment. This work has been supported by the CICYT (Ministerio de Educación y Ciencia, Grant PB86-0170). A FPI fellowship to one of us (M.B.) for the 1987–90 period is also deeply acknowledged. We thank the Servei de Microanàlisi and Servei d'Espectrometria de Masses (CSIC, Barcelona) for the elemental analyses and high-resolution mass spectra, respectively.

Registry No. **1a**, 40151-97-1; **1b**, 134781-66-1; **1c**, 134781-68-3; **1d**, 134781-67-2; **2**, 65371-24-6; **2** dimer (isomer 1), 134876-80-5; **2** dimer (isomer 2), 134876-82-7; **3**, 134781-56-9; **3** dimer (isomer 1), 134876-81-6; **3** dimer (isomer 2), 134876-83-8; **4**, 112-43-6; **5**, 14436-32-9; **6**, 134781-57-0; **7**, 134781-59-2; **8**, 134781-60-5; **9**, 134781-61-6; **10**, 134781-62-7; **11**, 134781-63-8; **12**, 106262-52-6; **13**, 134781-64-9; **14**, 76691-55-9; methyl 10-bromodecanoate, 134781-65-0; methyl 9-decenoate, 25601-41-6; pentachlorophenol, 87-86-5; *S*-2-pyridyl chlorothioformate, 73371-99-0; 11-bromo-1-undecene, 7766-50-9; 10-bromodecanoic acid, 50530-12-6.

Supplementary Material Available: Data for **10–14**; ^{1}H and ^{13}C NMR spectra of **6**, **9**, **11**, **12**, and **14** (11 pages). Ordering information is given on any current masthead page.

Synthesis of Alkynylcyclooctatetraenes and Alkynylcubanes

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The couplings of a variety iodocubanes with terminal acetylenes in refluxing NEt$_3$ in the presence of Cu(I) and Pd(0) were examined. The products, isolated in about 50% yield, were not alkynylcubanes but were instead the first examples of alkynyl-1,3,5,7-cyclooctatetraenes. The first examples of alkynylcubanes (cubylacetylenes) were themselves synthesized in modest yield by Negishi's procedure from alkyl cubyl ketones. Cubylacetylenes were shown to be stable under Heck-like coupling conditions and potentially useful thereby for the introduction of the cubylacetylene moiety into complex systems.

The discovery that ortho-metalation technology could be modified to apply to appropriately activated strained systems has made it possible to prepare a wide variety of substituted cubanes.[1] In this paper, with the same goal still in mind, we consider a different approach: transition metal catalyzed coupling reactions of halocubanes[2] with terminal acetylenes. The expected products, alkynylcubanes (cubylacetylenes), have not been reported previously; nothing is known of their chemistry.

The Heck reaction, in one or another of its forms, is a very useful method for carbon–carbon bond formation between unsaturated centers.[3] Sonogashira and Just and their co-workers have successfully adapted the method to the coupling of iodobenzene with terminal acetylenes.[4] This process is most efficient when both Cu(I) and Pd(II or 0) are present in catalytic amounts. The reactions probably proceed by palladium insertion into the carbon–iodine bond, nucleophilic displacement of a palladium ligand by a copper acetylide, and finally coupling with extrusion of palladium.[4a] Normally, saturated alkyl iodides are unsuitable participants as ionization and/or β-elimination reactions open pathways more-than-competitive with the desired coupling.

Although cubane is, representationally, a saturated hydrocarbon, there being four bonds to each carbon, the high percentage of s character in the cubane carbon exocyclic orbital implies a certain vinyl-like character in substituent bonding.[5] Ionization of cubyl halides, although possible,[6] is exceedingly difficult, and β-elimination to cubene (1,2-dehydrocubane), again although possible,[7] is a high-energy process unlikely under Heck reaction conditions. These substantial differences between cubyl halides and typical saturated halides encouraged us to attempt Heck coupling of cubyl halides with terminal acetylenes.

Application of the optimum conditions reported[8] for coupling of iodobenzene with terminal acetylenes (2 mol % Pd(PPh$_3$)$_4$, 3 mol % Cu$_2$Br$_2$, triethylamine, room temperature, excess of the acetylene) was ineffective when applied to a variety of iodocubanes. No coupling was observed with 1-hexyne or with phenylacetylene even after a 24 h reaction time; the starting iodides were recovered in good yield (80–90%). However, when the temperature was raised to near 90 °C (refluxing triethylamine), coupling reactions did occur, but did not give cubane-containing products. Instead, the reactions of substrates **1–5** with 1-hexyne or with phenylacetylene gave alkynyl-1,3,5,7-cyclooctatetraenes (**6–10**).[9] Relatively large amounts of metal catalysts were required [16 mol % Pd(0) and 24 mol % Cu(I)] for the conversion to be complete within 5 h. The reaction appears to be general with respect to both the iodocubane and the acetylene; about 50% isolated yields of alkynylcyclooctatetraenes were obtained no matter the variation in substrate or acetylene.

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[1] (a) Eaton, P. E.; Castaldi, G. *J. Am. Chem. Soc.* **1985**, *107*, 724. (b) Eaton, P. E.; Cunkle, G. T.; Marchioro, G.; Martin, R. M. *Ibid.* **1987**, *109*, 948. (c) Eaton, P. E.; Lee, C.-H.; Xiong, Y. *Ibid.* **1989**, *111*, 8016.

[2] Tsanaktsidis, J.; Eaton, P. E. *Tetrahedron Lett.* **1989**, *30*, 6967 and references therein.

[3] (a) Heck, R. F. *Org. React.* **1982**, *27*, 345. (b) Heck, R. F. *Pure Appl. Chem.* **1981**, *53*, 2323.

[4] (a) Sonogashira, K.; Tohda, Y.; Hagihara, N. *Tetrahedron Lett.* **1975**, *16*, 4467. (b) Just, G.; Singh, R. *Ibid.* **1987**, *28*, 5981.

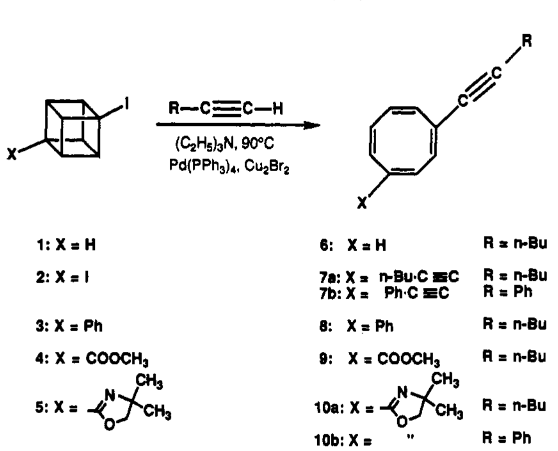
[5] Cole, T. W.; Jr. Dissertation, The University of Chicago, 1966, pp 48–52.

[6] Eaton, P. E.; Yang, C.-X.; Xiong, Y. *J. Am. Chem. Soc.* **1990**, *112*, 3225.

[7] Eaton, P. E.; Maggini, M. *J. Am. Chem. Soc.* **1988**, *110*, 7230.

[8] Singh, R.; Just, G. *J. Org. Chem.* **1989**, *54*, 4453.

[9] Dimers of the starting acetylene (a 2- to 4-fold excess was usually used) were also isolated. Cu(I) salts are known to promote the dimerization of acetylenes. See: Cadiot, P.; Chodkiewicz, W. In *Chemistry of Acetylenes*; Viehe, H. G., Ed.; Marcel Dekker: New York, 1969; Chapter 9.



To our knowledge, no acetylenic cyclooctatetraenes have been reported previously. Each of those made here (**6–10**) was purified by column chromatography and is a yellow, viscous oil. The structural assignments are based on spectroscopic information. The mass spectrum of each compound has a very prominent parent ion signal (quite unlike typical cubanes for which P^+ is very weak or missing). The presence of the acetylenic link is clear from the infrared streching absorption, weak but present in the 2100–2200-cm^{-1} region. The proton and carbon NMR spectra of **6–10** at room temperature are complex, but the presence of strong absorptions in the 5–6 ppm region made it immediately clear that the products were cyclooctatetraenes rather than cubanes (ca. 4 ppm). The 5–6 ppm region is a jumble of resonances, smeared over one another due to the presence of the interconverting 1,3,5,7-cyclooctatetraene valence-bond isomers and their conformers.[10] Raising or lowering the temperature significantly improved the situation.[10] In the simplest cases, those of symmetrically distributed materials (e.g., **7a**), lowering the sample temperature to −50 °C gave a spectrum with two sets (in the case of **7a** in a ratio of ca. 2:1) of four well-resolved signals for the vinyl carbons, corresponding to "frozen-out" valence bond or conformational isomers. Raising the temperature of the same sample to 105 °C gave an averaged ^{13}C NMR proton-decoupled spectrum with four well-separated signals in the olefin region. A 1,3-symmetrically disubstituted cyclooctatetraene would have five NMR-distinguishable carbons even under conditions of fast averaging; the 1,5 isomer would have three. Both other possible disubstitution patterns, 1,2 and 1,4, would give rise to four different COT carbon signals. Given that the substituents on the disubstituted cubanes used as starting materials were disposed 1,4, we suspected a similar disposition on the product cyclooctatetraenes. This was confirmed by an NMR study. The ^1H-coupled, ^{13}C NMR spectrum was used to show that the quaternary cyclooctatetraenyl carbon resonance for **7a** occurs at 127.1 ppm. The 2D-INADEQUATE spectrum (Figure 1) obtained from the same sample (280 mg of **7a** in 0.3 mL of *n*-octane-d_{18} at 105 °C) clearly demonstrated that this 127.1 ppm carbon is coupled to two different methines (J = 40 Hz). In a 1,2-homodisubstituted cyclooctatetraene, each quaternary COT carbon is next to only one methine carbon, whereas in the 1,4 isomer the quaternary carbons are each adjacent to two always-different methine carbons. It follows therefore that **7a** is 1,4-disubstituted. Rigorous de novo proof of the substitution pattern on any cyclooctatetrane is rarely available, and to our knowledge such has not been obtained for any case previously by NMR spectroscopic techniques.

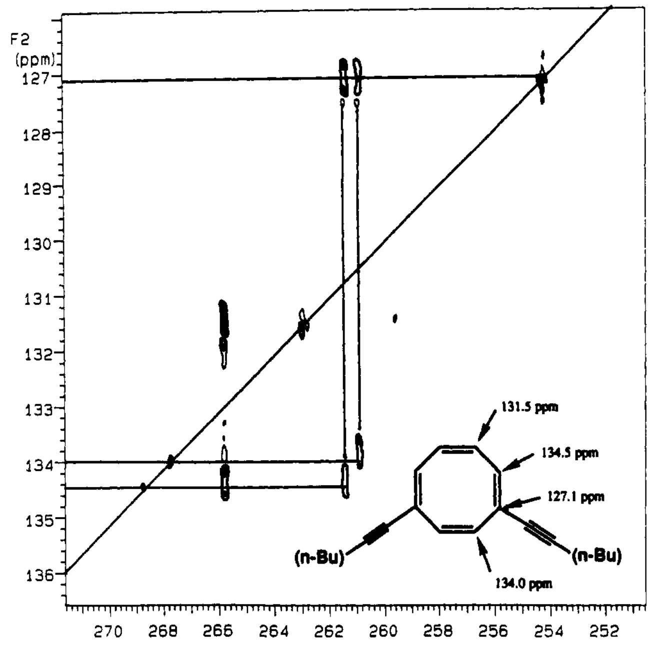


Figure 1. 2D-INADEQUATE ^{13}C spectrum of **7a** showing the vinyl region: 280 mg in 0.3 mL of *n*-octane-d_{18} at 105 °C; a 90° pulse with a 5.00-s delay was used; total acquisition time, 38 h at 100.6 MHz with 98 increments of 128 transients each (phase-sensitive mode).

Although it was disappointing that the coupling reactions tried failed to give cubylacetylenes, the reactions do have notable utility, constituting an effective synthesis of alkynylcyclooctatetraenes.[11] Indeed, general routes for the synthesis of 1,4-disubstituted cyclooctatetraenes are scarce,[12,13] and the problem of the direct attachment of an acetylenic unit (no less two) onto the cyclooctatetraene skeleton has not been addressed previously. The present method, albeit serendipitous, is particularly attractive as (a) a variety of alkynyl groups can be introduced, and (b) the starting iodocubanes are not very difficult to make.[2]

We have sought to understand the course of these wayward coupling reactions. As cubylacetylenes were previously unknown, there were doubts as to their stability. Such compounds might isomerize spontaneously (or in the presence of the catalyst system) to the energetically far-more-favorable cyclooctatetraenes. It was therefore imperative to effect their independent synthesis and characterization.

A number of routes were tried without success. Amongst those that failed were (a) Cassar's method for coupling iodobenzene to acetylenes [e.g., NaOMe, $Pd(PPh_3)_4$, and Cu_2Br_2 in DMSO at 130 °C];[14] (b) Ogawa's for coupling vinylic partners (CuI in HMPA);[15] and (c) Black's for coupling Grignards with bromoacetylenes [cobalt(II) chloride].[16] Two variants of the Stille modification[17] of

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[10] Anet, F. A. L.; Bourn, A. J. R.; Lin, Y. S. *J. Am. Chem. Soc.* **1964**, *86*, 3576.

[11] The recent interest in ring-opening metathesis polymerization of cyclooctatetraene increases the potential value of new cyclooctatetraenes.[24]

[12] For a review see: Paquette, L. A. *Tetrahedron* **1975**, *31*, 2855.

[13] The Rh(I)-catalyzed rearrangement of cubanes to *syn*-tricyclooctadienes and their thermal opening to to cyclooctatetraenes (Cassar, L.; Eaton, P. E.; Halpern, J. *J. Am. Chem. Soc.* **1970**, *92*, 6366) can be used to prepare substituted cyclooctatetraenes). Eaton, P. E.; Chou, C.-T., unpublished observations.

[14] Cassar, L. *J. Organomet. Chem.* **1975**, *93*, 253.

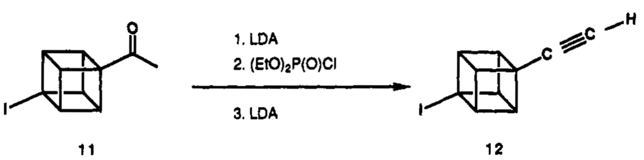
[15] Ogawa, T.; Kusume, K.; Tanaka, M.; Hayami, K.; Suzuki, H. *Synth. Commun.* **1989**, *19*, 2199.

[16] Black, H. K.; Horn, D. H. S.; Weedon, B. C. L. *J. Chem. Soc.* **1954**, 1704.

the Heck reaction were tried, but neither the admixture of cubane 1 with 1-hexynyltri-*n*-butyltin in refluxing triethylamine containing $Pd(PPh_3)_4$ and Cu_2Br_2 nor that at 50 °C in THF containing $Pd(PPh_3)_2Cl_2$ resulted in coupling. Application of the Negishi method[18] for coupling trialkynylalanes and easily ionizable halides was not expected to work, as it would have involved the high energy cubyl cation; it did not. Save one, all these attempts gave no evidence of any reaction when applied to iodocubanes; CuI in HMPA at room temperature did decompose the cubyl system in a complex, unproductive way.

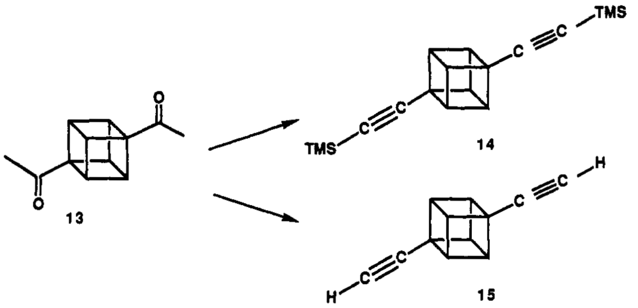
Faced with these discouraging results we turned away from coupling reactions and looked instead to simple functional group manipulations. Vinylcubane can be prepared readily by Wittig methenylation of cubyl aldehyde.[19] The compound is stable, but bromination (preparatory to double dehydrobromination) results in a cubyl-to-homocubyl rearrangement typical of cubyl carbinyl cationic species and is therefore useless for the purpose at hand.

Negishi et al. have developed a mild method for the synthesis of terminal acetylenes from methyl ketones.[20] When applied to cubyl methyl ketones,[21] this did provide alkylnylcubanes in modest, but sufficient yields. For example, treatment of methyl 4-iodocubyl ketone (11) with LDA in THF gave the enolate, which was trapped with diethyl chlorophosphate; subsequent elimination with LDA gave (4-iodocubyl)acetylene (12), isolated in 32% yield after purification.



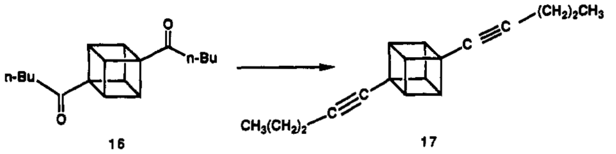
11 12

The conversion of 1,4-diacetylcubane (13) was also successful, although the yield was low. In this case, it was first feared that the expected product, 1,4-diethynylcubane (15), would be too volatile for easy isolation. Therefore, chlorotrimethylsilane was added to the reaction mixture before aqueous workup to give the bis(trimethylsilyl) derivative 14. This was isolated pure in 9% yield. Later we were to find that 15 itself could be isolated directly.



13 14 15

The Negishi procedure has not (to our knowledge) been reported useful in the making of internal acetylenes. Nonetheless, we were able to take diketone 16 (prepared by reaction of lithium di-*n*-butylcuprate with the diacid chloride of 1,4-dicarboxycubane) to the bis(1-pentynyl)cubane 17 in 5% yield.



16 17

The NMR spectra of symmetrical cubyldiacetylenes are strikingly simple. The cubyl signals in the ^1H NMR spectra fall within a relatively narrow range, 3.9–4.3 ppm, close to the resonance of cubane itself (4.00 ppm). All of the cubylacetylenes we have made to date are stable, white crystalline materials with sharp melting points (except 15, which decomposes above 160 °C). They are not at all prone to spontaneous isomerization or decay. (This is indeed generally the case with cubanes. The system, although very highly strained and thermodynamically unfavorable, is usually stable kinetically.) We must look elsewhere to explain the formation of alkynylcyclooctatetraenes instead of alkynylcubanes in the attempted Heck coupling reactions.

Silver salts cause cubane to rearrange readily at room temperature to cuneane.[22] Rhodium(I) complexes effect ready cleavage of cubane to *syn*-tricyclooctadiene, which can isomerize thermally (fast at 60 °C) to cyclooctatetraene.[13] Might it be that the metal catalysts in the attempted coupling reactions are rearranging the starting iodocubanes and/or the alkynylcubanes that might have been formed?[23] Many test experiments were run. The iodocubanes 1, 2, and 5 proved to be stable under reflux in NEt_3 for at least 5 h, with or without Cu_2Br_2, $Pd(PPh_3)_4$, or a mixture of the two present. Similarly, the diacetylene 17 was found to be stable under the same set of reaction conditions and to those used for the conversion of 2 to **7a**.

Although these results are clear proof that iodocubanes and alkynylcubanes are not sensitive to ring opening with Cu(I) or Pd(0), it might be that during an actual Heck coupling one or another of the organometallic intermediates formed could catalyze a cubane-to-cyclooctatetraene rearrangement. However, when iodocubane 2 and alkynylcubane 17 together were teated with 1-heptyne, $Pd(PPh_3)_4$, and Cu_2Br_2 in refluxing triethylamine the cubyl iodide was totally converted to the coupled hexynylcyclooctatetraene, whereas the alkynylcubane was unchanged. We can only conclude that somewhere along the course of Heck coupling of an iodocubane to a terminal acetylene there is formed an intermediate particularly prone to intramolecular rearrangement of its cubane framework. We have tried to identify this intermediate using ^1H NMR spectroscopy to trace the reaction of an

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(17) (a) Stille, J. K.; Simpson, J. H. *J. Am. Chem. Soc.* **1987**, *109*, 2138. (b) Stille, J. K. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 508.

(18) Negishi, E.; Baba, S. *J. Am. Chem. Soc.* **1975**, *97*, 7385.

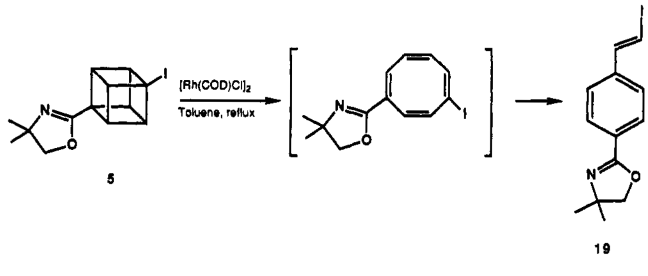
(19) Eaton, P. E.; Zhou, J. P., unpublished work.

(20) (a) Negishi, E.; King, A. O.; Tour, J. M. *Org. Synth.* **1986**, *64*, 44. (b) Negishi, E.; King, A. O., Klima, W. L. *J. Org. Chem.* **1980**, *45*, 2526.

(21) These are easily made from the corresponding acids; see the Experimental Section.

(22) Cassar, L.; Eaton, P. E.; Halpern, J. *J. Am. Chem. Soc.* **1970**, *92*, 3515.

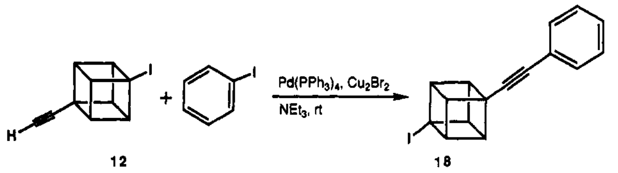
(23) Incidentally, we note that when cubyl iodide 5 was heated for 24 h in toluene in the presence of 7 mmol % $(Rh(COD)Cl)_2$, styrene 19 was formed (70% yield after purification). This can be rationalized: Rh(I) will catalyze rearrangement of 5 to the tricyclooctadiene, which will then open thermally to the iodocyclooctatetraene; it has been demonstrated (Huisgen, R.; Konz, W. E. *J. Am. Chem. Soc.* **1970**, *92*, 4102, 4104, 4105) that bromocyclooctatetraene rearranges to *trans*-β-bromostyrene on heating at 80 °C.



5 19

iodocubane mixed with stoichiometric amounts of Heck reagents. However, under such conditions the conversion is far too fast for us to follow.

While trying to unravel the course of these reactions, we observed incidentally that coupling of (4-iodocubyl)acetylene (**12**) with iodobenzene in the presence of 4 mol % of $Pd(PPh_3)_4$ and 6 mol % of Cu_2Br_2 *at room temperature* in NEt_3 was very effective. It was complete within 3 h, and we were able to isolate 1-(4-iodocubyl)-2-phenylacetylene (**18**) in 90% yield. This demonstrates that a cubylacetylene behaves as any other terminal acetylene in the Heck reaction and that (at least at room temperature) the presence of an iodine substituent on the cubane nucleus neither impedes nor redirects normal Heck coupling. Acetylene **18** is an interesting building block for the synthesis of complex systems; it might be used for the introduction of the cubane unit into "natural" molecules or provide (via cubane ring opening reactions) interesting new cyclooctatetraenes or polyacetylenes therefrom.[24]



Experimental Section

NMR spectra were run in chloroform-*d* at ambient probe temperature unless otherwise noted: ^{1}H NMR at 400 MHz and referenced to internal tetramethylsilane (δ 0.00 ppm) or chloroform (δ 7.24 ppm); ^{13}C NMR spectra at 100.6 MHz and referenced to the central line of the solvent. Proton chemical shifts are reported to a precision of ±0.02 ppm; coupling constants are reported to a precision of ±1 Hz. Carbon chemical shifts are given to a precision of ±0.1 ppm. FT-IR spectra were obtained at a digital resolution of 1 cm^{-1}. Standard NMR and GLC criteria were used to establish that products were better than 90% pure; typical impurities were water and residual solvents. FT-IR spectra were obtained at a digital resolution of 1 cm^{-1}. UV spectra are reported to a precision of ±5 nm. EI (70 ev) low-resolution mass spectra were obtained directly on eluates from a OV-17-coated capillary column; major ions are reported to unit mass (intensity parenthetically as a percent of the strongest peak above m/z 40). Merck silica gel 60 (230–400 mesh) was used for column chromatography; solvent polarity was chosen so that the desired component had an R_f value of 0.2–0.3. TLC was done on precoated (SiO_2, 0.25 mm) Polygram, G/UV 254 plastic sheets. THF was distilled from sodium benzophenone ketyl immediately prior to use. Triethylamine and diisopropylamine were refluxed with CaH_2 for 5 h and then distilled from CaH_2. Specialty chemicals were purchased from Aldrich, unless otherwise stated. All glassware was vacuum oven-dried before use; reactions were routinely run under N_2. Iodocubanes **1–5** were prepared according to published procedures.[2]

General Procedure for the Preparation of Alkynyl-1,3,5,7-cyclooctatetraenes (6–10) from Iodocubanes (1–5). A solution of the iodocubane (1.00 mmol) in NEt_3 (10.0 mL) was refluxed under N_2 with the terminal acetylene (4.00 mmol), $Pd(PPh_3)_4$ (0.16 mmol, 185 mg), and Cu_2Br_2 (0.24 mmol, 69 mg) until no starting material was present as judged by TLC (usually 6 h). The solvent was removed under reduced pressure, and the residue was passed through a short column of silica gel with diethyl ether. The eluate was concentrated under reduced pressure, and the residue was dissolved in acetonitrile (10 mL). H_2O_2 (30%, 0.5 mL) was added to convert triphenylphosphine to its easily removed oxide. The mixture was stirred for 5 min. Ether (50 mL) was added; the organic layer was separated, washed with water (4 × 30 mL), dried over $MgSO_4$, and concentrated under reduced pressure. Purifications were accomplished by open column or preparative thin-layer chromatography using 100% *n*-hexane as eluent for **6–9** and 5/95 v/v EtOAc/*n*-hexane for **10a,b**. The products were yellow oils; yields were all about 50%.

1-Hexynyl-1,3,5,7-cyclooctatetraene (6): UV (CH_3CN) λ 266 nm (19100); IR (neat) ν 3006 (s), 1492 (m), 814 (m), 797 (s), 733 cm^{-1} (s); ^{1}H NMR (−50 °C) δ 7.50–7.40 (m, 2 H), 7.38–7.28 (m, 3 H), 6.36–6.30 (m, 1 H), 6.01–5.85 ppm (m, 6 H); ^{13}C NMR (−50 °C) δ 137.8, 132.6, 132.4, 131.8, 131.5, 131.4, 131.0, 130.7, 128.2, 124.8, 122.3, 89.2, 89.2, 87.0 ppm; MS m/z 204 (M^{+}, 95), 203 (96), 202 (100), 101 (22).

1,4-Bis(1-hexynyl)-1,3,5,7-cyclooctatetraene (7a): UV (CH_3CN) λ 240 (24500), 315 nm (2700); IR (neat) ν 2957 (m), 2930 (m), 2220 (vw), 1645 cm^{-1} (s); ^{1}H NMR δ 6.20–5.90 (m, 2 H), 5.90–5.65 (m, 4 H), 2.27 (t, J = 7 Hz, 4 H), 1.54–1.33 (m, 8 H), 0.88 ppm (t, J = 7 Hz, 6 H); ^{13}C NMR (−50 °C) δ 136.0, 135.1, 131.6, 131.5, 131.3, 131.2, 125.4, 124.9, 89.9, 89.2, 80.2, 30.4, 22.0, 19.0, 13.8 ppm; ^{13}C NMR (105 °C, *n*-octane-d_{18}, vinyl region) δ 134.5, 134.0, 131.5, 127.1 ppm; MS m/z 264 (M^{+}, 72), 221 (36), 179 (100), 178 (96), 165 (95).

1,4-Bis(phenylacetynyl)-1,3,5,7-cyclooctatetraene (7b): UV (CH_3CN) λ 276 (29700), 320 nm (10100); IR (neat) ν 3015 (m), 2202 (w), 1490 (s), 754 (s), 689 cm^{-1} (s); ^{1}H NMR (acetone-d_6, −50 °C) δ 7.46–7.26 (m, 10 H), 6.42–6.30 (m, 2 H), 6.10–5.86 ppm (m, 4 H); ^{1}H NMR δ 7.6–7.1 (m, 10 H), 6.4–5.8 ppm (m, 6 H); ^{13}C NMR (acetone-d_6, −50 °C) δ 138.5, 137.3, 132.9, 132.4, 132.2, 132.0, 131.8, 129.5, 129.4, 129.3, 126.3, 125.2, 123.0, 123.0, 90.0, 89.7, 88.7, 88.2 ppm; MS m/z 304 (M^{+}, 55), 303 (53), 302 (100), 261 (26), 226 (31).

1-(1-Hexynyl)-4-phenyl-1,3,5,7-cyclooctatetraene (8): UV (CH_3CN) λ 236 (22600), 312 nm (3100); IR (neat) ν 2957 (s), 2931 (s), 2219 (w), 1492 (m), 779 (m), 695 cm^{-1} (s); ^{1}H NMR δ 7.44–7.20 (m, 5 H), 6.30–5.84 (m, 6 H), 2.40–2.24 (m, 2 H), 1.60–1.40 (m, 4 H), 0.95 ppm (t, J = 7 Hz, 3 H); ^{13}C NMR (acetone-d_6, −70 °C) δ 141.0, 140.2, 138.8, 138.6, 136.1, 135.7, 132.2, 132.1, 131.9, 131.8, 131.5, 131.0, 130.0, 128.0, 127.4, 127.3, 127.0, 126.3, 125.4, 125.2, 124.8, 124.7, 88.1, 88.0, 80.2, 80.0, 30.0, 21.3, 17.9, 12.8 ppm; ^{13}C NMR δ 13.6, 19.0, 22.0, 30.7, 55.9, 59.5, 80.8, 89.0, 125.4, 125.7, 126.2, 126.9, 127.6, 128.3, 130.4, 131.3, 132.0, 132.2, 132.4, 132.5, 132.6, 132.8, 136.0, 136.5, 139.8, 141.7, 142.2 ppm; MS m/z 260 (M^{+}, 54), 217 (72), 215 (93), 203 (80), 202 (100), 189 (34), 115 (57).

1-Carbomethoxy-4-(1-hexynyl)-1,3,5,7-cyclooctatetraene (9): UV (CH_3CN) λ 232 (14900), 325 nm (1800); ^{1}H NMR δ 7.03 (s, 1 H), 6.15–5.70 (m, 5 H), 3.75 (s, 3 H), 2.30 (d, J = 7 Hz, 2 H), 1.68–1.38 (m, 4 H), 0.91 ppm (t, J = 7 Hz, 3 H); ^{13}C NMR δ 166.2, 142.2, 141.2, 135.2, 133.8, 133.3, 133.1, 133.0, 132.6, 131.8, 131.5, 130.3, 129.4, 129.0, 128.0, 126.2, 90.7, 89.6, 80.5, 52.0, 30.6, 21.9, 19.0, 13.6 ppm; MS m/z 242 (M^{+}, 56), 227 (8), 211 (7), 199 (17), 183 (44), 167 (40), 153 (77), 141 (100), 139 (93), 128 (42), 115 (59).

1-(4,4-Dimethyl-2-oxazolino)-4-(1-hexynyl)-1,3,5,7-cyclooctatetraene (10a): UV (CH_3CN) λ 233 nm (11100); IR (neat) δ 2961 (s), 2931 (s), 2220 (w), 1643 (m), 1029 cm^{-1} (s); ^{1}H NMR δ 6.64 (m, 1 H), 6.12–5.73 (m, 5 H), 3.93 (s, 2 H), 2.29–2.23 (m, 2 H), 1.50–1.40 (m, 2 H), 1.40–1.33 (m, 2 H), 1.27 (s, 6 H), 0.90–0.86 ppm (t, J = 7 Hz, 3 H); ^{13}C NMR (acetone-d_6, −40 °C) δ 13.8, 19.0, 22.4, 28.1, 28.2, 28.4, 28.5, 31.0, 31.1, 68.2, 68.2, 78.6, 81.3, 89.4, 90.2, 126.4, 127.5, 130.7, 131.0, 131.4, 131.6, 132.1, 132.3, 132.4, 132.5, 132.8, 135.2, 136.2, 136.3, 137.5, 160.8 ppm; ^{13}C NMR δ 13.6, 19.1, 22.0, 28.3, 30.7, 67.7, 78.8, 80.6, 80.8, 89.6, 90.2, 126.2, 127.2, 129.3, 129.9, 130.4, 130.7, 131.7, 131.8, 132.3, 132.6, 133.1, 134.3, 135.2, 136.3, 137.2, 161.2, 161.4 ppm; MS m/z 281 (M^{+}, 100), 280 (95), 238 (30), 139 (25).

1-(4,4-Dimethyl-2-oxazolino)-4-(phenylacetynyl)-1,3,5,7-cyclooctatetraene (10b): UV (CH_3CN) λ 287 (19000), 316 nm (7500); IR (neat) ν 2968 (s), 2200 (w), 1644 (s), 1610 (s), 1490 (m), 1296 (s), 1029 (s), 756 (s), 690 cm^{-1} (s); ^{1}H NMR δ 7.58–7.20 (m, 5 H), 6.77–6.67 (m, 1 H), 6.35–5.80 (m, 5 H), 3.96 (s, 2 H), 1.28 ppm (s, 6 H); ^{13}C NMR (−50 °C) δ 160.8, 160.6, 137.1, 136.7, 135.9, 135.8, 132.6, 132.4, 132.2, 131.9, 131.4, 131.3, 131.0, 130.5, 130.4, 129.7, 129.6, 129.3, 128.4, 128.2, 128.1, 126.0, 125.0, 122.2, 122.0, 90.5, 90.1, 89.6, 89.4, 88.9, 88.8, 88.5, 87.9, 78.3, 67.5, 67.4, 31.3, 28.3, 28.0 ppm; MS m/z 301 (M^{+}, 100), 300 (83), 246 (32). Anal. Calcd for $C_{21}H_{19}NO$: C, 83.70; H, 6.36. Found: C, 83.90; H 6.82.

4-Iodocubyl Methyl Ketone (11). 4-Iodocubane-1-carboxylic acid (1.26 g, 4.60 mmol) was stirred under N_2 at rt with thionyl chloride (10 mL) for 30 min. The excess reagent was removed under reduced pressure at rt. The residue, crude 4-iodocubane-1-carbonyl chloride, was dried at 1 mm for 1 h. Separately,

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[24] See, for example: Gorman, C. B.; Ginsburg, E. J.; Marder, S. R.; Grubbs, R. H. *Angew. Chem. Adv. Mater.* **1989**, *101*, 1603.

a suspension of dry CuI (14.0 mmol, 2.67 g) in anhydrous THF (40 mL) was cooled to −78 °C. MeLi (27.0 mmol, 19.3 mL of a 1.4 M solution in ether) was added dropwise. The mixture was stirred at 0 °C for 40 min and then cooled to −78 °C. A solution of 4-iodocubane-1-carbonyl chloride (from the crude described above, 4.6 mmol, 1.34 g) in dry THF (10 mL) was added dropwise. Stirring was continued at −78 °C for 20 min. Absolute methanol (5 mL) was carefully added at −78 °C, and the mixture was allowed gradually to reach rt. Water (5 mL) was added, and the organic layer was separated, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Column chromatography with 1/9 v/v EtOAc/*n*-hexane afforded **11** as a white solid (0.94 g, 75%): mp 125–126 °C; IR (KBr) ν 2989 (w), 1678 (s), 1362 (m), 1314 (m), 1214 (m), 1197 (m), 1025 (m), 783 cm^{-1} (m); ^1H NMR δ 4.42 (m, 3 H), 4.27 (m, 3 H), 2.13 ppm (s, 3 H); ^{13}C NMR δ 205.3, 63.5, 54.2, 50.1, 36.1, 24.8 ppm; MS *m/s* 272 (M^+, 0.5), 229 (3), 102 (100).

(4-Iodocubyl)acetylene (12). This procedure follows from that in the literature developed for other systems.[22] *n*-BuLi (2.50 mmol, 1.50 mL of a 1.64 M solution in hexanes) was added dropwise to a well-stirred solution of diisopropylamine (0.35 mL, 2.5 mmol) in dry THF (4 mL) at 0 °C. This LDA solution was stirred at 0 °C for 20 min and then cooled to −78 °C. A solution of iodo ketone **11** (0.9 mmol, 245 mg) in dry THF (4 mL) was added dropwise, and the reaction mixture was stirred for 1 h at −78 °C. Diethyl chloro phosphate (2.50 mmol, 0.36 mL) was added at −78 °C, and the mixture (mixture A) was warmed to rt over 3 h. Separately, another solution of LDA was prepared in dry THF (5 mL) from diisopropylamine (6.0 mmol, 0.84 mL) and *n*-BuLi (6.00 mmol, 3.65 mL of a 1.64 M solution in hexanes). This solution was stirred at 0 °C for 20 min and then cooled to −78 °C. Mixture A was added slowly (9 min), and the whole was allowed to reach rt over 3 h. It was then cooled to 0 °C, and water (4 mL) was added. The organic layer was separated, and the aqueous layer was extracted with ether (3 × 30 mL). The combined organic phase was washed with 1 N hydrochloric acid (50 mL) and then saturated aq $NaHCO_3$ (2 × 50 mL). It was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Purification by column chromatography with 95/5 v/v *n*-hexane/EtOAc furnished **12** as a white solid (73 mg, 32%): mp 163–164 °C; IR (KBr) ν 3288 (s), 2999 (w), 2988 (w), 2100 (w), 1032 (s), 790 (s), 623 cm^{-1} (s); ^1H NMR δ 4.28–4.20 (m, 6 H), 2.87 ppm (s, 1 H); ^{13}C NMR δ 82.5, 78.5, 54.7, 51.8, 46.0, 36.3 ppm; MS m/z 254 (M^+, 0.2), 204 (28), 127 (100), 126 (91), 102 (27). Anal. Calcd for $C_{10}H_7I$: C, 47.27; H, 2.78. Found: C, 47.58; H, 2.71.

1,4-Diacetylcubane (13). This diketone was prepared (720 mg, 80%) from the reaction of cubane-1,4-dicarbonyl chloride and Me_2CuLi (6 equiv per mmol of diacid chloride) in dry THF as described for the synthesis of **16** (vide infra) save that methyllithium was substituted for butyllithium. During workup, the washings with water must be avoided since the product is soluble in the aqueous phase. Purification by recrystallization from diethyl ether provided **13** as a white solid: mp 154–155.5 °C; IR (KBr) ν 3010 (m), 1680 (s), 1364 (m), 1317 cm^{-1} (m); ^1H NMR δ 4.20 (s, 1 H), 2.10 ppm (s, 1 H); ^{13}C NMR δ 205.6, 63.6, 46.5, 24.8 ppm; MS *m/z* 188 (M^+, 4), 173 (1), 145 (20), 131 (12), 115 (22), 103 (27), 102 (23), 43 (100).[25]

1,4-Bis((trimethylsilyl)acetynyl)cubane (14) was prepared from diketone **13** (4.00 mmol, 752 mg) with a procedure similar to the preparation of **12** except that chlorotrimethylsilane (excess, 5.0 mL) at 0 °C was used instead of water to quench the reaction mixture. After the addition of TMSCl, the mixture was stirred overnight at rt, and then 5 % aqueous $NaHCO_3$ (60 mL) was added. Purification by column chromatography eluting with *n*-hexane gave **14** as a white solid (9%, 118 mg): mp 173–174 °C; IR (KBr) ν 2957 (w), 2148 (m), 1251 (m), 833 cm^{-1} (s); ^1H NMR δ 4.02 (s, 1 H), 0.15 ppm (s, 3 H) ppm; ^{13}C NMR δ 105.4, 93.8, 49.1, 46.5, 0.2 ppm; MS *m/z* 296 (M^+, 42), 281 (68), 159 (84), 73 (100).

1,4-Bis(ethynyl)cubane (15) was prepared from diketone **13** (4.00 mmol, 752 mg) as described for the synthesis of **12**. Purification by column chromatography furnished **15** as a white solid (10%, 61 mg): decomposition above 160 °C; IR (KBr) ν 3293 (s), 3283 (s), 3007 (m), 2998 (m), 2987 (m), 2097 (m), 620 cm^{-1} (s); ^1H NMR δ 4.05 (s, 6 H), 2.81 ppm (s, 2 H); ^{13}C NMR ($CDCl_3$) δ 83.2, 77.4, 48.7, 45.8 ppm; MS *m/z* 152 (M^+, 9), 151 (72), 102 (100), 76 (30).

1,4-Bis(pentanoyl)cubane (16). 1,4-Bis(carbomethoxy)cubane (Enichem Synthesis, 3.00 g, 13.6 mmol) was refluxed with 5.0 g of NaOH in 50 mL of water for 3 h. The solution was cooled and acidified at 0 °C with concd. hydrochloric acid to pH 1 (not lower). The white precipitate (cubane-1,4-diacid) was collected and washed with water until the pH of the filtrate was neutral. The solid was dried for 4 h at 50 °C at 1 mm and then refluxed with stirring with 10 mL of pure $SOCl_2$ for 2 h. The excess reagent was removed under reduced pressure at rt (do not heat!), and the white solid residue, cubane-1,4-dicarbonyl chloride, was dried at 1 mm for 1 h. Separately, a suspension of anhydrous CuI (1.14 g, 6.00 mmol) or $CuBr{\cdot}Me_2S$ (6.00 mmol, 1.23 g) was prepared in anhydrous ether (15 mL), and the mixture was cooled to −78 °C. *n*-BuLi (12.0 mmol, 7.30 mL of a 1.64 M solution in hexanes) was added dropwise. The mixture was stirred at −20 °C (CCl_4/dry ice bath) for 45 min and then cooled to −78 °C. A solution of cubane-1,4-dicarbonyl chloride (1.00 mmol, 230 mg) in dry THF (5 mL) was added dropwise. Stirring was continued at −78 °C for 20 min. Absolute methanol (2 mL) was carefully added at −78 °C, and the mixture was allowed gradually to reach rt. Saturated aqueous NH_4Cl was added (40 mL), and the mixture was extracted with ether (4 × 30 mL). The extract was washed with water (3 × 50 mL), dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Column chromatography with 1/9 v/v EtOAc/*n*-hexane afforded the title compound (86%, 233 mg) as a colorless oil: IR (neat) ν 2958 (s), 2932 (s), 2873 (m), 1685 (s), 1371 cm^{-1} (m); ^1H NMR δ 4.23 (s, 6 H), 2.44 (t, J = 8 Hz, 4 H), 1.58 (m, 4 H), 1.33 (m, 4 H), 0.92 ppm (t, J = 7 Hz, 6 H); ^{13}C NMR δ 207.8, 62.9, 46.5, 37.4, 25.1, 22.1, 13.5 ppm; MS *m/z* 272 (M^+, 71), 188 (63), 146 (100), 131 (43), 85 (94), 57 (82).

1,4-Bis(1-pentynyl)cubane (17) was prepared like **12** but from diketone **16** (0.90 mmol, 245 mg). Purification by column chromatography eluting with *n*-hexane gave **17** (5%, 10 mg) as a white solid: mp 156–157 °C; IR (KBr) ν 2362 (m), 2225 (vw), 1464 (s), 1269 (s), 1202 cm^{-1} (s); ^1H NMR δ 3.94 (s, 6 H), 2.25 (t, J = 7 Hz, 4 H), 1.52 (sextet, J = 7 Hz, 4 H), 0.97 ppm (t, J = 7 Hz, 6 H); ^{13}C NMR δ 89.9, 79.9, 48.8, 46.7, 22.3, 21.3, 13.4 ppm; MS *m/z* 236 (M^+, 42), 207 (57), 191 (65), 178 (78), 165 (100), 152 (46), 129 (42). Anal. Calcd for $C_{18}H_{20}$: C, 91.45; H, 8.53. Found: C, 91.13; H, 8.63.

1-(4-Iodocubyl)-2-phenylacetylene (18). (4-Iodocubyl)acetylene (**12**, 50 mg, 0.20 mmol), iodobenzene (0.06 mL, ca. 0.5 mmol), $Pd(PPh_3)_4$ (4 mmol % with respect to the acetylene, 10 mg), and Cu_2Bu_2 (6 mmol %, 4 mg) were stirred together overnight under N_2 at rt in dry NEt_3 (3 mL). The excess amine was removed under reduced pressure; the residue was purified by column chromatography, eluting with *n*-hexane. Compound **18** was obtained as a white solid (90%, 60 mg): mp 138–139 °C; IR (KBr) ν 3010 (s), 2209 (w), 1653 (m), 1958 (m), 1442 (s), 1182 cm^{-1} (s); ^1H NMR δ 7.40 (m, 2 H), 7.29 (m, 3 H), 4.29 ppm (broad s, 6 H); ^{13}C NMR δ 131.2, 128.2, 127.9, 123.2, 90.6, 87.8, 54.8, 52.5, 46.8, 36.7 ppm; MS *m/z* 330 (M^+, 100), 202 (70), 101 (16). Anal. Calcd for $C_{16}H_{11}I$: C, 58.21; H, 3.36. Found: C, 57.77; H, 3.18.

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Supplementary Material Available: ^1H NMR and ^{13}C NMR spectra of compounds 11 and 13–16 (11 pages). Ordering information is given on any current masthead page.

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(25) This material was first prepared and characterized by Cheng-Xi Yang of this Laboratory.