JOC*Note*

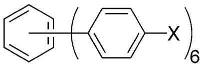
Syntheses of Hexakis(4-functionalized-phenyl)benzenes and Hexakis[4-(4′-functionalized-phenylethynyl)phenyl]benzenes Directed to Host Molecules for Guest-Inclusion Networks

Kenji Kobayashi,*,[†] Norifumi Kobayashi,[†]
Masahiro Ikuta,[†] Bruno Therrien,[‡]
Shigeru Sakamoto,[‡] and Kentaro Yamaguchi[‡,§]

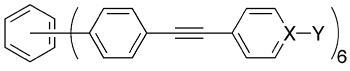
Department of Chemistry, Faculty of Science, Shizuoka University, 836 Ohya, Shizuoka 422-8529, Japan, and Chemical Analysis Center, Chiba University, Inage-ku, Chiba 263-8522, Japan

skkobay@ipc.shizuoka.ac.jp

Received August 23, 2004



1a: X = CN
1b: X = NHCOC$_7$H$_{15}$-*n*
1c: X = NH$_2$
1d: X = NHCONHC$_8$H$_{17}$-*n*
1e: X = I
1f: X = B(OH)$_2$



2a: X = C, Y = CN
2b: X = N
2c: X = C, Y = OTBS
2d: X = C, Y = CO$_2$Et
2e: X = C, Y = OH
2f: X = C, Y = CO$_2$H

The syntheses of various types of hexakis(4-functionalized-phenyl)benzenes **1** and hexakis[4-(4′-functionalized-phenylethynyl)phenyl]benzenes **2** by the cobalt-catalyzed cyclotrimerization of diarylacetylenes and by the Sonogashira coupling reaction of **1e** with arylacetylenes, respectively, are described. X-ray crystallographic analysis showed that host **1e** or **2f** forms a 2-D network by unique I···I or CH···O=C interactions, respectively.

Hexaarylbenzene derivatives have attracted considerable attention in the field of materials science as precursors for graphite-like, dendritic, or photoconductive polycyclic aromatic hydrocarbons,[1,2] or as a scaffold for a starlike array of functional materials such as porphyrin.[3] Hexaarylbenzene derivatives also serve as guest-inclusion organic crystals directed to organic zeolites. Recently, we have reported the 2-D or 3-D hydrogen-bonded networks of hexakis(4-hydroxyphenyl)benzene,[4a] hexakis(4-carboxyphenyl)benzene,[4b] and hexakis(4-carbamoylphenyl)benzene[4c] with guest-inclusion ability. These are highly symmetrical molecules that can support six radial hydrogen-bonding sites for the formation of a predictable network with cavity based on multipoint cooperative interactions, and exhibit an orthogonal arrangement of the interactive moieties with respect to the central benzene core, the strategy of which can prevent network interpenetration. As a next generation, we have planned to introduce various types of interactive groups on the hexaarylbenzenes for the construction of new networks with guest-inclusion ability and to expand the cavities of their networks.[5] Here we report the syntheses of various types of hexakis(4-functionalized-phenyl)benzenes **1** and hexakis[4-(4′-functionalized-phenylethynyl)phenyl]benzenes **2** (Chart 1) directed to forming host molecules for guest-inclusion networks in the solid state.

The Co$_2$(CO)$_8$-catalyzed cyclotrimerization[1,4] of bis(4-cyanophenyl)acetylene or bis[4-(octanoylamino)phenyl]acetylene produced hexakis(4-cyanophenyl)benzene[6] (**1a**) (80% yield) or hexakis[4-(octanoylamino)phenyl]benzene (**1b**) (97% yield), respectively (Scheme 1). The hydrolysis of **1b** by 6 M HCl gave hexakis(4-aminophenyl)benzene (**1c**) (67% yield), which was converted by octyl isocyanate to hexakis[4-(*N*′-octylureido)phenyl]benzene (**1d**) (94% yield). The 6-fold iodination of hexaphenylbenzene with [bis(trifluoroacetoxy)iodo]benzene[7] and I$_2$ gave hexakis(4-iodophenyl)benzene (**1e**) (79% yield, Scheme 2), which is an alternative method for the reaction of hexakis(4-trimethylsilylphenyl)benzene with ICl.[8] The 6-fold lithiation of **1e** by *n*-BuLi followed by reaction with B(OMe)$_3$ gave hexakis[4-(dihydroxyboryl)phenyl]benzene (**1f**) (57% yield).[9] It is expected to form a 2-D metal-coordinated network for **1a** and a 2-D or 3-D hydrogen-bonded network with guest-inclusion ability for **1b**, **1d**, and **1f**. It is also expected to serve as a precursor of an expanded hexaarylbenzene derivative for **1c**, **1e**, and **1f**.

Next, the 6-fold Sonogashira coupling reaction of **1e** with 4-functionalized-phenylacetylenes in Et$_3$N−THF in the presence of PdCl$_2$(PPh$_3$)$_2$, CuI, and PPh$_3$ (18 mol % each) was carried out to synthesize hexakis[4-(4′-functionalized-phenylethynyl)phenyl]benzenes **2** (Scheme 3).[8,10] Thus, 4-cyanophenylethynyl (**2a**), 4-pyridylethynyl (**2b**), 4-(*tert*-butyldimethylsilyloxy)phenylethynyl (**2c**), and

---

[†] Shizuoka University.

[‡] Chiba University.

[§] Present address: Faculty of Pharmaceutical Sciences at Kagawa Campus, Tokushima Bunri University, Shido, Sanuki, Kagawa 769-2193, Japan.

(1) (a) Berresheim, A. J.; Müller, M.; Müllen, K. *Chem. Rev.* **1999**, *99*, 1747−1785. (b) Watson, M. D.; Fechtenkötter, A.; Müllen, K. *Chem. Rev.* **2001**, *101*, 1267−1300.

(2) (a) Ito, S.; Wehmeier, M.; Brand, J. D.; Kübel, C.; Epsch, R.; Rabe, J. P.; Müllen, K. *Chem. Eur. J.* **2000**, *6*, 4327−4342. (b) Schmidt-Mende, L.; Fechtenkötter, A.; Müllen, K.; Moons, E.; Friend, R. H.; MacKenzie, J. D. *Science* **2001**, *293*, 1119−1122. (c) Wu, J.; Watson, M. D.; Müllen, K. *Angew. Chem., Int. Ed.* **2003**, *42*, 5329−5333.

(3) Takase, M.; Ismael R.; Murakami, R.; Ikeda, M.; Kim, D.; Shinmori, H.; Furuta, H.; Osuka, A. *Tetrahedron Lett.* **2002**, *43*, 5157−5159.

(4) (a) Kobayashi, K.; Shirasaka, T.; Sato, A.; Horn, E.; Furukawa, N. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 3483−3486. (b) Kobayashi, K.; Shirasaka, T.; Horn, E.; Furukawa, N. *Tetrahedron Lett.* **2000**, *41*, 89−93. (c) Kobayashi, K.; Sato, A.; Sakamoto, S.; Yamaguchi, K. *J. Am. Chem. Soc.* **2003**, *125*, 3035−3045.

(5) (a) Sada, K.; Sugahara, M.; Kato, K.; Miyata, M. *J. Am. Chem. Soc.* **2001**, *123*, 4386-4392. (b) Holman, K. T.; Martin, S. M.; Parker, D. P.; Ward, M. D. *J. Am. Chem. Soc.* **2001**, *123*, 4421−4431. (c) Biradha, K.; Hongo, Y.; Fujita, M. *Angew. Chem., Int. Ed.* **2002**, *41*, 3395−3398.

(6) Sakon, Y.; Ohnuma, T.; Hashimoto, M.; Saito, S.; Tsutsui, T.; Adachi, C. U.S. Patent 5077142, 1991.

(7) Merkushev, E. B.; Simakhina, N. D.; Koveshnikova, G. M. *Synthesis* **1980**, 486−487.

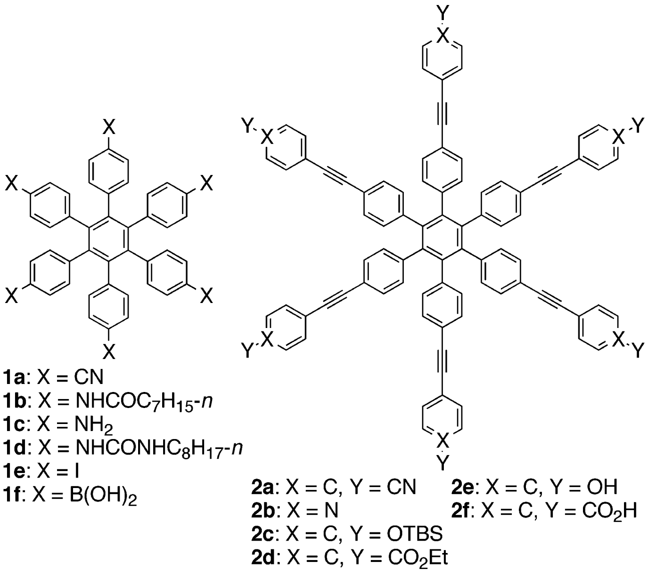
(8) Hyatt, J. A. *Org. Prep. Proced. Int.* **1991**, *23*, 460−463.

(9) For tetrakis[4-(dihydroxyboryl)phenyl]methane, see: Fournier, J.-H.; Maris, T.; Wuest, J. D.; Guo, W.; Galoppini, E. *J. Am. Chem. Soc.* **2003**, *125*, 1002−1006.

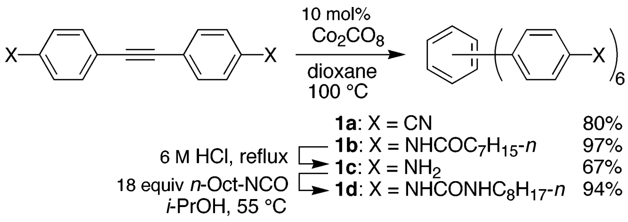
(10) (a) Takahashi, S.; Kuroyama, Y.; Sonogashira, K.; Hagihara, N. *Synthesis* **1980**, 627−629. (b) Sonogashira, K. In *Metal-catalyzed Cross-coupling Reactions*; Diederich, F., Stang, P. J., Eds.; Wiley-VCH: Weinheim, Germany, 1998; Chapter 5.

10.1021/jo048521i CCC: $30.25

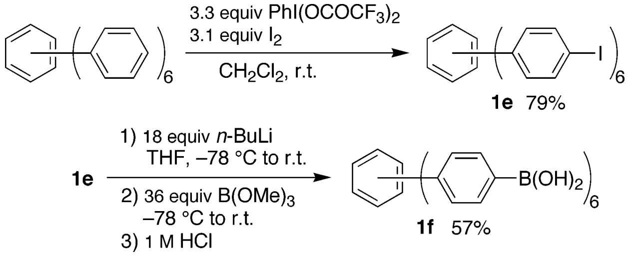
CHART 1



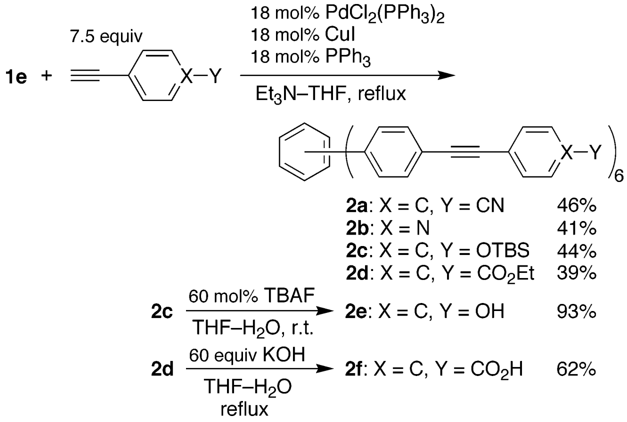
SCHEME 1



SCHEME 2



SCHEME 3



4-(ethoxycarbonyl)phenylethynyl (**2d**) groups were introduced at the para position of hexaphenylbenzene in 46%, 41%, 44%, and 39% yields, respectively. The deprotection of **2c** by TBAF or **2d** by KOH gave hexakis[4-(4′-hydroxyphenylethynyl)phenyl]benzene (**2e**) (93% yield) or hexakis[4-(4′-carboxyphenylethynyl)phenyl]benzene (**2f**) (62% yield), respectively. It is expected to form a 2-D metal-coordinated or hydrogen-bonded expanded network with guest-inclusion ability for **2a** and **2b** or **2e** and **2f**, respectively.

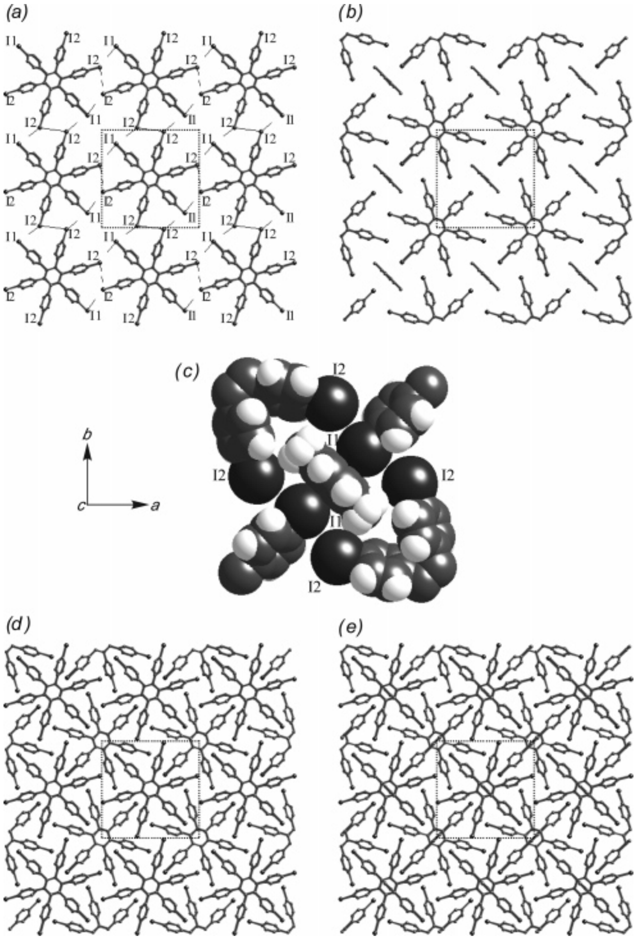


FIGURE 1. X-ray crystal structure of **1e**·*p*-xylene as viewed down along the *c* axis: a 2-D sheet of **1e** (a) without and (b) with *p*-xylenes; (c) one cleft of **1e** with *p*-xylene; and a packing diagram of several 2-D sheets of **1e** (d) without and (e) with *p*-xylene. All hydrogen atoms, except in part c, are omitted for clarity.

Single crystals of **1e** suitable for X-ray diffraction analysis were obtained as **1e**·*p*-xylene by slow diffusion of *p*-xylene into a solution of **1e** in nitrobenzene.[11] Host **1e** forms a 2-D network sheet by two types of iodine···iodine interactions (Figure 1a). One type is an attractive iodine−iodine interaction with a distance of I1···I2 = 4.273 Å, and the other type is a close-packing contact with a distance of I2···I2′ = 4.290 Å.[12] It is known that the I atom is polarized $\delta(+)$ in the polar region and $\delta(-)$ in the equatorial region of the C−I bond.[12] Although these I···I contact distances are somewhat longer than twice the Bondi's van der Waals radius of the I atom,[13] the contact angles of C−I1···I2 = 82.61° and C−I2···I1

---

(11) Crystal data for **1e**·*p*-xylene: tetragonal, $P4_22_12$, $a = 15.627(3)$ Å, $c = 9.717(3)$ Å, $V = 2373.0(9)$ Å^3, $Z = 2$, $T = 173$ K, $R = 0.059$, $R_w = 0.152$ ($I > 2\sigma(I)$), and $GOF = 1.07$. Crystal data for **2f**·7(MeOH): triclinic, $P\bar{1}$, $a = 11.637(4)$ Å, $b = 13.290(4)$ Å, $c = 18.076(5)$ Å, $\alpha = 92.762(4)°$, $\beta = 102.061(4)°$, $\gamma = 111.491(4)°$, $V = 2519.9(12)$ Å^3, $Z = 2$, $T = 100$ K, $R = 0.097$, $R_w = 0.134$ ($I > 3\sigma(I)$), and $GOF = 2.49$.

= 142.93° are consistent with a polarization interaction between I atoms of type II defined by Desiraju, and the contact angle of C−I2···I2′ = 80.96° is consistent with a close-packing contact of type I.[12b,e,f] As shown in parts b and c of Figure 1, four molecules of **1e** in the 2-D network sheet produce a cleft surrounded by six iodine atoms, in which one molecule of *p*-xylene is accommodated by a two-point I···π interaction with an I1···phenyl ring center distance of 3.272 Å,[12d,e] and by a four-point CH···I interaction with an H···I2 distance of 3.162 Å (C···I2 = 4.050 Å).[14] The somewhat longer I···I contact distances could arise from the inclusion of *p*-xylene in the iodine−iodine network of **1e**. The adjacent 2-D network sheets are a center of inversion to each other, and are layered in an ···ABAB··· sequence along the *c* axis with a sheet-to-sheet distance of 4.86 Å (Figure 1a,b,d). Consequently, *p*-xylene that is accommodated in a cleft of the 2-D network sheet is sandwiched between two central benzene cores of **1e** in the adjacent upper and lower 2-D sheets (core-to-core distance of 9.713 Å) by edge-to-face $\pi-\pi$ (CH−π) interaction with a closest C···C distance of 3.716 Å (Figure 1a,b,e, also see Supporting Information).

Single crystals of **2f** suitable for X-ray diffraction analysis were obtained as **2f**·7(MeOH) by slow evaporation of a solution of **2f** and 4 equiv of pyrene in MeOH−$CHCl_3$.[11] Pyrene was not included in the crystal lattice of **2f**. In marked contrast to hexakis(4-carboxyphenyl)benzene (**3**), which forms a 2-D hydrogen-bonded network with large triangular cavities (one side of ca. 15.2 Å) based on a hydrogen-bonded carboxylic acid dimer,[4b] the expanded host **2f** has not produced a similar network to that of **3** at this stage. An appropriate guest molecule fitting the size and shape of a hypothetical cavity of **2f** (one side of ca. 30 Å) might be required to maintain a similar network to that of **3**. Figure 2a shows an actual 2-D sheet of **2f**. A hydrogen-bonded carboxylic acid dimer of **2f** is broken by six CO_2H···HOMe hydrogen bonds (with distances O1···O13 = 2.573 Å, O3···O8 = 3.082 Å, O3···O10 = 3.095 Å, and O5···O11 = 2.601 Å), and by a self-interdigitation of **2f** so as to reduce the void space. In contrast to **3**, the 2-D sheet of **2f** is stabilized by face-to-face $\pi-\pi$ stacking and CH···O=C interactions between benzoic acid moieties (Figure 2b),[14a] wherein the close distances between aromatic carbon atoms and carbonyl oxygen atoms are 3.364 and 3.492 Å for C···O2 and 3.420 and 3.479 Å for C···O4. The 2-D sheets of **2f** are layered in an ···ABAB··· sequence along the *a* axis to give a rectangular channel of 8.5 × 3.5 Å as a cross section, including van der Waals radii (Figure 2c).

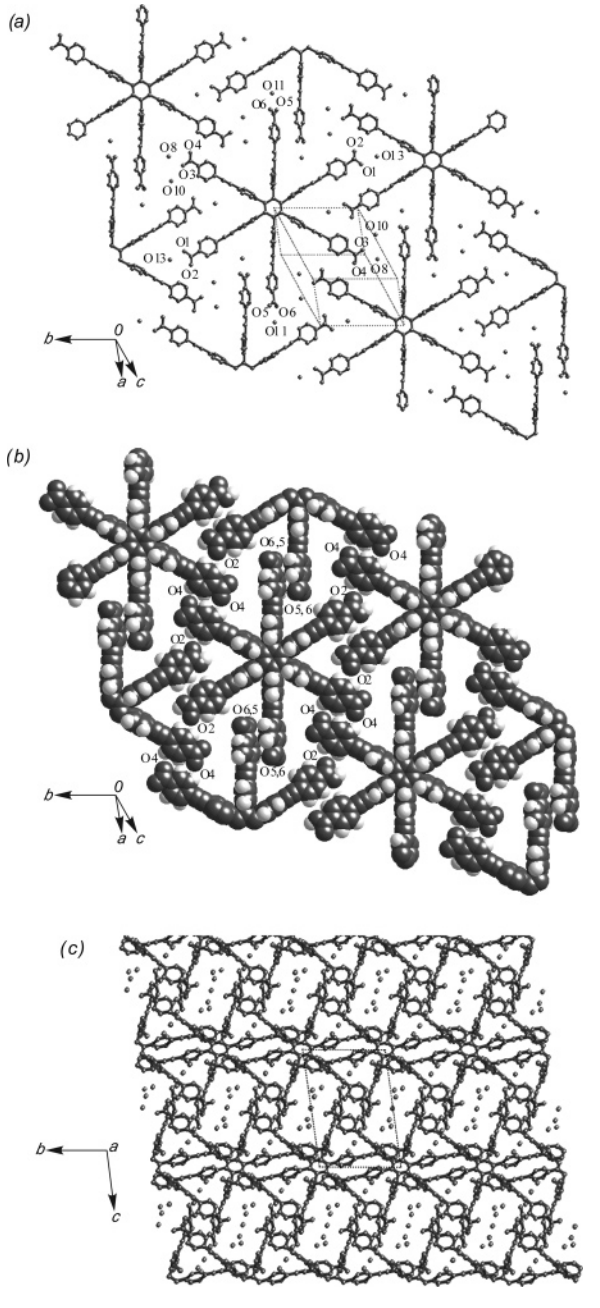


FIGURE 2. X-ray crystal structure of **2f**·7(MeOH): (a) a 2-D sheet of **2f** with hydrogen-bonded MeOH; (b) a 2-D sheet of **2f** without MeOH; and (c) packing diagram of several 2-D sheets of **2f** with MeOH as viewed down along the *a* axis. All hydrogen atoms, non-hydrogen-bonded MeOH, and carbon atoms of hydrogen-bonded MeOH for part a, all MeOH for part b, and all hydrogen atoms and all carbon atoms of MeOH for part c are omitted for clarity.

In summary, we have demonstrated the syntheses of various types of hexakis(4-functionalized-phenyl)benzenes **1** and hexakis[4-(4′-functionalized-phenylethynyl)-phenyl]benzenes **2**. Studies on the formation of 2-D or 3-D hydrogen-bonded or metal-coordinated networks with guest-inclusion ability based on hosts **1** and **2** are underway, directed toward organic or organic−inorganic hybrid zeolite analogues.[15]

---

(12) (a) Ramasubbu, N.; Parthasarathy, R.; Murray-Rust, P. *J. Am. Chem. Soc.* **1986**, *108*, 4308−4314. (b) Pedireddi, V. R.; Reddy, D. S.; Goud, B. S.; Craig, D. C.; Rae, A. D.; Desiraju, G. R. *J. Chem. Soc., Perkin Trans. 2* **1994**, 2353−2360. (c) Price, S. L.; Stone, A. J.; Lucas, J.; Rowland, R. S.; Thornley, A. E. *J. Am. Chem. Soc.* **1994**, *116*, 4910−4918. (d) Reddy, D. S.; Craig, D. C.; Desiraju, G. R. *J. Am. Chem. Soc.* **1996**, *118*, 4090−4093. (e) Thaimattam, R.; Reddy, D. S.; Xue, F.; Mak, T. C. W.; Nangia, A.; Desiraju, G. R. *New J. Chem.* **1998**, 143−148. (f) Bosch, E.; Barnes, C. L. *Cryst. Growth Des.* **2002**, *2*, 299−302. (g) Logothetis, T. A.; Meyer, F.; Metrangolo, P.; Pilati, T.; Resnati, G. *New J. Chem.* **2004**, *28*, 760−763.

(13) Twice the van der Waals radius of I atom is 3.96 Å by Bondi and 4.30 Å by Pauling. (a) Bondi, A. *J. Phys. Chem.* **1964**, *68*, 441−451. (b) Pauling, L. *The Nature of the Chemical Bond*, 3rd ed.; Cornell University Press: Ithaca, NY, 1960.

(14) (a) Desiraju, G. R. *Acc. Chem. Res.* **2002**, *35*, 565−573. (b) Gibb, C. L. D.; Stevens, E. D.; Gibb, B. C. *J. Am. Chem. Soc.* **2001**, *123*, 5849−5850. (c) Kobayashi, K.; Ishii, K.; Sakamoto, S.; Shirasaka, T.; Yamaguchi, K. *J. Am. Chem. Soc.* **2003**, *125*, 10615−10624.

Acknowledgment. We thank Prof. G. R. Desiraju (University of Hyderabad) for valuable discussion on the halogen−halogen interactions. This work was supported in part by a Grant-in-Aid from the Ministry of Education, Science, Sports, Culture, and Technology, Japan (No. 14340217).

Supporting Information Available: Experimental procedures and spectral data for **1** and **2**, and ORTEP views and crystallographic information files (CIF) for **1e** and **2f**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO048521I

---

(15) (a) Aoyama, Y. *Top. Curr. Chem.* **1998**, *198*, 131−161. (b) Yaghi, O. M.; O'Keeffe, M.; Ockwig, N. W.; Chae, H. K.; Eddaoudi, M.; Kim, J. *Nature* **2003**, *423*, 705−714.