

**Complexation of a Carbon Nanoring with Fullerenes\*\***

Takeshi Kawase,\* Kenji Tanaka, Naoki Fujiwara,  
Hossein R. Darabi, and Masaji Oda\*

*Dedicated to Emeritus Professor Soichi Misumi  
on the occasion of his 77th birthday*

Recently, a variety of layered carbon networks with closed, curved structures, such as carbon nanotubes,<sup>[1]</sup> bucky onions,<sup>[2]</sup> and “fullerene peapods”<sup>[3]</sup> have been discovered and have attracted much attention. Although the nature of the concave–convex interactions between the curved graphene sheets should be important in the formation and properties of these materials, they are yet to be well understood because of the absence of good model compounds. There have been considerable efforts towards the synthesis of belt-shaped conjugated systems.<sup>[4,5]</sup> In the accompanying paper,<sup>[6]</sup> we reported that the carbon nanorings [6]- and [8]paraphenyleneacetylene (**1** and **2**) have cavities with diameters of 13.2 and 17.3 Å, respectively (average values determined by X-ray diffraction), and form rather weak inclusion complexes with hexamethylbenzene and toluene, respectively. The size of the cavity in **1** appears to be suitable for the inclusion of C<sub>60</sub> (7.1 Å in diameter), although it is actually slightly too small when the depth of p orbitals (3.4 Å for benzene) is considered (Figure 1). Therefore, the host–guest chemistry of **1** with fullerenes would give an insight into the concave–convex  $\pi$ – $\pi$  interactions that are associated with the bucky onion and fullerene peapod. Here, we report on the formation of unusually stable complexes of the carbon nanoring **1** with C<sub>60</sub> and bis(ethoxycarbonyl)methanofullerene (**3**),<sup>[7]</sup> and X-ray crystallographic analysis of the crystalline 1:1 complex **1**·**3**.

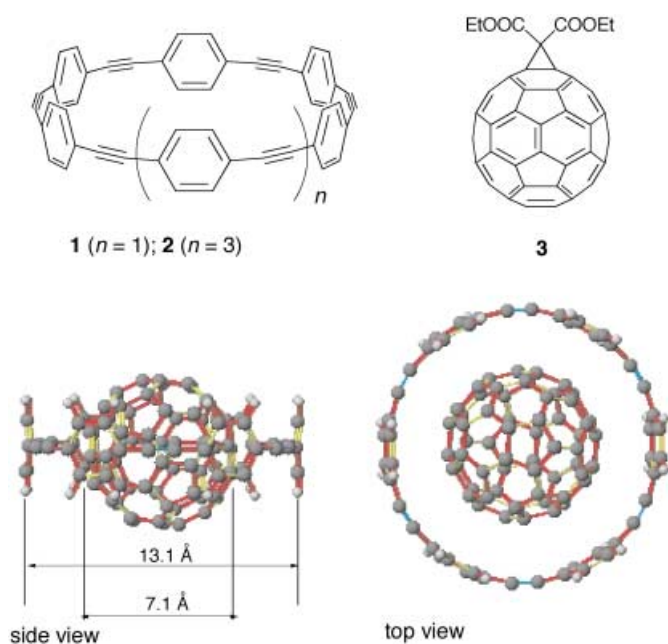
Despite being only sparingly soluble in CHCl<sub>3</sub>,<sup>[8]</sup> C<sub>60</sub> was found to be much more soluble (approximately 5 mg per mL) in the presence of **1**, to give the 1:1 complex **1**·C<sub>60</sub> as a reddish brown solution, or a dark red-brown solid which precipitated out at higher concentrations. The solid complex could be redissolved completely in CHCl<sub>3</sub>, which is in sharp contrast to the behavior of the solid calix[8]arene–C<sub>60</sub> complex,<sup>[9,10]</sup> where C<sub>60</sub> remained undissolved when added to CHCl<sub>3</sub>;

[\*] Prof. Dr. T. Kawase, Prof. Dr. M. Oda, K. Tanaka, N. Fujiwara,  
Dr. H. R. Darabi  
Department of Chemistry  
Graduate School of Science, Osaka University  
Toyonaka, Osaka 560-0043 (Japan)  
Fax: (+81) 6-6850-5387  
E-mail: tkawase@chem.sci.osaka-u.ac.jp  
moda@chem.sci.osaka-u.ac.jp

[\*\*] This work was supported by a Grant-in-Aid for Scientific Research (No. 10146102 and 14340197) and from the Ministry of Education, Science, Sports, and Culture, Japan. We thank Dr. Hirose (Osaka University) for helpful discussion.



Supporting information for this article is available on the WWW under <http://www.angewandte.org> or from the author.

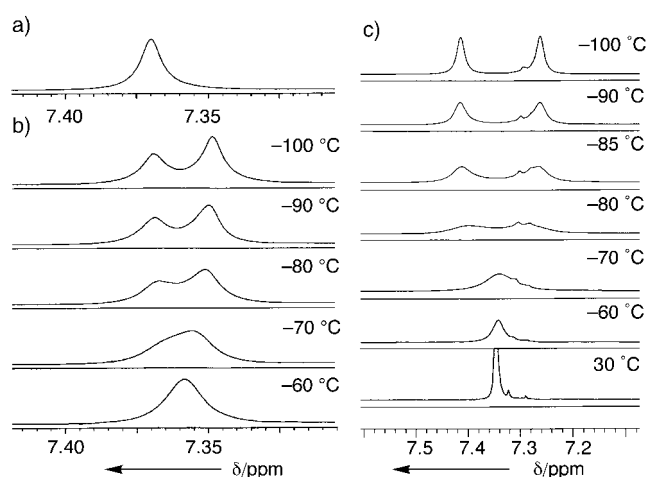


**Figure 1.** Paraphenyleneacetylenes **1** and **2**, fullerene derivative **3**, and a possible molecular structure of **1**- $C_{60}$ .

these results suggest that a much higher association constant exists between **1** and  $C_{60}$  in  $CHCl_3$ . A similar procedure also afforded the 1:1 complex **1**·**3**. In contrast, the larger carbon nanoring **2** did not show any degree of complexation with either type of fullerene.

The interactions between **1** and  $C_{60}$  in solution were examined by absorption spectroscopy. Gradual addition of **1** to a solution of  $C_{60}$  in benzene causes a gradual change in the absorption spectrum. The isosbestic point at 583 nm, as well as a continuous-variation (Job's) plot,<sup>[11]</sup> provides evidence for a 1:1 complex in solution. The association constant ( $K_a$ ) of the **1**- $C_{60}$  complex, as determined by Hirose's method,<sup>[12]</sup> is  $(1.6 \pm 0.3) \times 10^4 \text{ dm}^3 \text{ mol}^{-1}$ . The absorption spectra of **1**·**3** also showed some variation, but the changes were too small for the measurement of a reliable association constant.

$^1\text{H}$  NMR spectroscopy at low temperature afforded further important information (Figure 2). The spectrum of a solution of  $C_{60}$  and **1** (1:2.5) in  $CD_2Cl_2$  exhibits a sharp singlet at 7.36 ppm for the aromatic protons at 30 °C. However, the signal broadens as the temperature is lowered and splits into two singlets which can be assigned to the protons of complex **1**- $C_{60}$  (7.37 ppm), and the free host **1** (7.35 ppm) at  $-100^\circ\text{C}$  (Figure 2b). This dynamic behavior was not observed in  $[D_8]\text{toluene}$ . In-and-out motion of  $C_{60}$  against the cavity of **1** in  $CD_2Cl_2$  is thus fast at room temperature and becomes slow enough for the NMR timescale at lower temperatures. Importantly, the  $^1\text{H}$  NMR spectrum of the isolated **1**- $C_{60}$  complex, thus an exact 1:1 ratio of two components, exhibits only the signal of the complex at  $-100^\circ\text{C}$  (Figure 2a). Taking the concentration of **1**- $C_{60}$  ( $2.2 \times 10^{-4} \text{ mol dm}^{-3}$ ) and possible detection of the free host **1** (down to 2%) into account, the value for  $K_a$  between **1** and  $C_{60}$  is estimated to be very large (exceeding  $10^7 \text{ dm}^3 \text{ mol}^{-1}$ ).<sup>[13]</sup> Variable-temperature NMR experiments also reveal that the Gibbs activation energy ( $\Delta G^\ddagger$ ) for dissociation of **1**- $C_{60}$  is  $(9.9 \pm 0.3) \text{ kcal mol}^{-1}$  ( $T_c =$

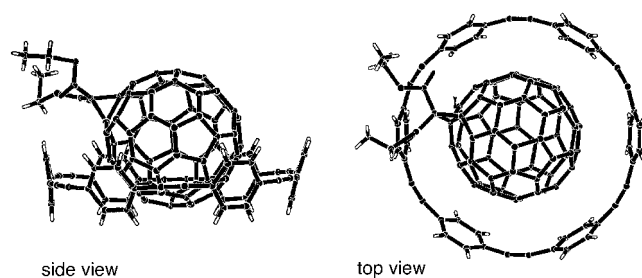


**Figure 2.**  $^1\text{H}$  NMR spectra of a) **1**- $C_{60}$  (0.22 mmol  $\text{dm}^{-3}$ ; isolated as a solid) at  $-100^\circ\text{C}$ ; b) a 1:2.5 mixture of **1** and  $C_{60}$ ; c) a 1:1 mixture of **1** and **3**.

$(-80 \pm 5)^\circ\text{C}$ ) in  $CD_2Cl_2$ . The appearance of all the protons as a singlet points to near standstill or fast vibration of the  $C_{60}$  molecule around the center of the cavity and also its fast rotation inside the cavity, even at  $-100^\circ\text{C}$ . Moreover, a 1:1 mixture of **1** and **3** in  $CD_2Cl_2$  showed a sharp singlet at 7.38 ppm for the aromatic protons of **1** at room temperature, a broadened singlet as the temperature was lowered, and finally two singlets (7.26 and 7.42 ppm) of equal intensity at  $-100^\circ\text{C}$  (Figure 2c). The appearance of two singlets is consistent with a lowering in the symmetry of **3**. The value of  $\Delta G^\ddagger$  for dissociation was calculated to be  $(9.4 \pm 0.2) \text{ kcal mol}^{-1}$  ( $T_c = -78 \pm 3^\circ\text{C}$ ) which is a little lower than that of **1**- $C_{60}$ . Thus, the **1**·**3** complex is slightly less stable than its **1**- $C_{60}$  counterpart.

X-ray crystallographic analysis of these crystalline complexes should provide definitive information on their structures. However, attempted X-ray analyses of the **1**- $C_{60}$  complex have so far failed to give adequate diffraction data, probably because of rotation of the guest molecules. Actually, a CP-MAS-NMR spectrum of the **1**- $C_{60}$  complex at  $30^\circ\text{C}$  shows a singlet peak (143.2 ppm) for  $C_{60}$  in the solid state. On the other hand, good single crystals of the **1**·**3** complex, suitable for X-ray analysis, were obtained from a toluene solution by slow evaporation of the solvent.<sup>[14]</sup> The molecular structure obtained reveals that each molecule of the complex is associated with two toluene molecules (Figure 3), and that the  $C_{60}$  cage of **3** is not deeply embedded in the cavity of **1** but situated at a floating position away from the center of the cavity, which takes on a bowl-shaped conformation. Even in this "ball-on-bowl" structure, all of the benzene rings of **1** are facing the  $C_{60}$  cage of **3**. The ester groups of **3** lean on the aromatic rings of **1**, and therefore the aromatic protons of nanoring **1** act like a gear wheel hindering easy rotation of the guest.

Table 1 lists the structural parameters of **1** in the complex **1**·**3** compared with those of the complex with hexamethylbenzene (**1**-HMB).<sup>[6]</sup> These data are almost identical except for the twist angles of the aromatic rings. The bond lengths and angles of **3** in this complex are also almost identical to those of the known structural data of **3**.<sup>[7c]</sup> There are



**Figure 3.** Molecular structure of **1·3**. Toluene molecules are omitted for clarity.

**Table 1:** Structural parameters of **1** in inclusion complexes.

	<b>1·HMB</b>	<b>1·3</b>
long axis [Å]	13.3	13.3
short axis [Å]	13.0	13.0
average bond angles of sp carbon atoms [°]	162.5 $\approx$ 165.6 (164.4)	162.2 $\approx$ 166.2 (164.5)
twist angles of benzene rings [°] <sup>[a]</sup>	−9, 1, 17	20.3, 14.8, 16.9, 19.6, 16.5, 5.1
bend angles of benzene rings [°] <sup>[b]</sup>	151.9, 149.2, 149.5	153.0, 151.6, 150.9, 149.0, 148.4, 148.1

[a] Evaluated from dihedral angles between least-square planes. [b] The angles between the two *para*-benzyl bonds of each boat-form benzene ring.

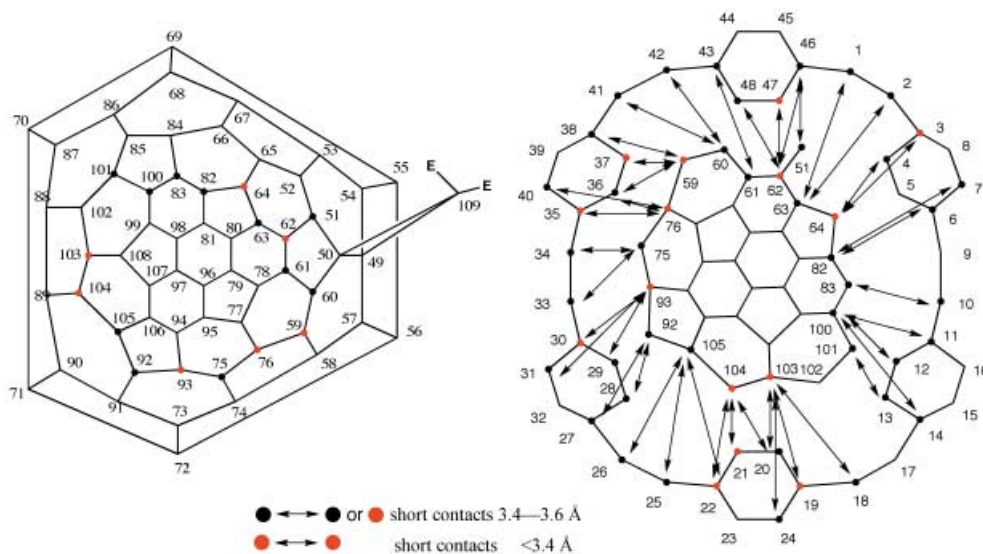
altogether 41 short interatomic distances ( $< 3.6$  Å) and eight particularly short contacts ( $< 3.4$  Å) between the host and guest (Figure 4). There are, however, no short contacts between the  $C_{60}$  cage and the outer surface of **1**. Most of the carbon atoms of **1** (37 out of 48) are in close contact with the  $C_{60}$  cage of **3**. The average distance between the host and guest is roughly estimated to be 3.4 Å, which is almost equal to the interlayer distance of multiwall carbon nanotubes. Taking into account the van der Waals distance between  $sp^2$  carbon atoms (3.4 Å), the diameter of **1** (13.2 Å) seems a little too small to allow  $C_{60}$  to be fully embedded, and therefore the

floating position of **3** would be a consequence of energetic favoring. Therefore, the singlet signal of **1·C<sub>60</sub>** and the two singlets of **1·3** in their NMR spectra at  $-100^\circ\text{C}$  suggest that fast vibrational motion of the  $C_{60}$  molecule around the center of the cavity is evident, even at such a low temperature.

The short contacts seem to bear little correlation with the molecular orbital interaction between the HOMO of **1** and the LUMO of **3**.<sup>[7b]</sup> For example, although the C(103)⋯C(19) separation is the shortest contact of its type (3.26 Å), C(103) has no coefficient in the LUMO orbital. It is noteworthy that all the benzene rings of **1** lie over the [5:6] ring fusions of the  $C_{60}$  cage, which represent centers of positive charge on the  $C_{60}$  surface.<sup>[15,16]</sup>

According to many studies,<sup>[17–20]</sup> noncovalent interactions between aromatic rings have been explained in terms of van der Waals (dispersion force) and polar electrostatic (PE) interactions rather than as charge-transfer interactions. The high affinity between **1** and  $C_{60}$  cannot be explained in terms of dispersion forces alone because the complex of **1** and hexamethylbenzene described before,<sup>[6]</sup> where the dispersion force would be expected to play a greater role, is almost dissociated in nonpolar solvents. Charge-transfer effects would also be negligible because **1** has poor electron-donating properties (the first electrochemical oxidation potential is over +1.0 V in  $\text{CH}_2\text{Cl}_2$ ), and only a slight change is observed in the charge-transfer absorption band (450–650 nm) in every case. In contrast, the complex of  $C_{60}$  with *N,N*-dimethylaniline exhibits a rather intense charge-transfer absorption band.<sup>[21]</sup> Thus, the PE interaction remains the most probable driving force for complexation.

Theoretical studies have predicted that curved aromatic hydrocarbons should be polarized with regard to their convex and concave faces because  $\pi$  systems on a curved surface suffer an anisotropic distribution of  $\pi$  electrons, which results in the segregation of electrostatic charge.<sup>[22]</sup> However, the results of theoretical calculations have been controversial as to the direction of polarization.<sup>[22c]</sup> The significantly strong complexation found here between **1** and fullerenes, as well as the good face-to-face solvating ability of benzene and



**Figure 4.** The short contacts between the host and guest in the **1·3** complex.

alkylbenzenes, may be understood by assuming the electronic potential of the convex surface of the fullerenes to be positive.<sup>[16a]</sup> An electrostatic attractive force, namely, a quadrupolar–quadrupolar interaction between the electrostatically opposite concave and convex surfaces, as well as the dispersion force, would play an important role in the formation of complexes between **1** and fullerenes,<sup>[23]</sup> and hence the spontaneous formation of layered carbon nanotubes, bucky onions, and fullerene peapods.

Received: December 9, 2002 [Z50728]

**Keywords:** cyclophanes · fullerenes · host–guest systems · inclusion compounds · noncovalent interactions

- [1] a) S. Iijima, *Nature* **1991**, 354, 56–58; b) S. Iijima, T. Ichibashi, Y. Ando, *Nature* **1992**, 356, 776–778; c) P. M. Ajayan, S. Iijima, *Nature* **1993**, 361, 333–334; d) A. Thess, R. Lee, P. Nikolaev, H. Dai, P. Petit, J. Robert, C. Xu, Y. H. Lee, S. G. Kim, A. G. Rinzler, D. T. Colbert, G. E. Scuseria, D. Tomanek, J. E. Fischer, R. E. Smalley, *Science* **1996**, 273, 483–487.
- [2] a) H. W. Kroto, *Science* **1988**, 242, 1139–1145; b) D. Ugarte, *Nature* **1992**, 359, 707–709.
- [3] B. W. Smith, M. Monthieux, D. E. Luzzi, *Nature* **1998**, 396, 323–324.
- [4] The synthetic challenges for belt-shaped conjugated systems: a) F. Vögtle, *Top. Curr. Chem.* **1983**, 115, 157–159; b) P. R. Ashton, N. S. Isaacs, F. H. Kohnke, A. M. Z. Slawin, C. M. Spencer, J. F. Stoddart, D. J. Williams, *Angew. Chem.* **1988**, 100, 981–983; *Angew. Chem. Int. Ed. Engl.* **1988**, 27, 966–969; c) F. Diederich, Y. Rubin, C. B. Knobler, R. L. Whetten, K. E. Schriver, K. N. Houk, Y. Li, *Science* **1989**, 245, 1088–1090; d) Y. Rubin, C. B. Knobler, F. Diederich, *J. Am. Chem. Soc.* **1990**, 112, 1607–1617; e) Y. Tobe, T. Fujii, H. Matsumoto, K. Naemura, Y. Achiba, T. Wakabayashi, *J. Am. Chem. Soc.* **1996**, 118, 2758–2759; f) R. Friederich, M. Neiger, F. Vögtle, *Chem. Ber.* **1993**, 126, 1723–1732; g) R. M. Cory, C. L. McPhail, A. J. Dikmans, J. J. Vittal, *Tetrahedron Lett.* **1996**, 37, 1983–1986; h) R. M. Cory, C. L. McPhail, *Tetrahedron Lett.* **1996**, 37, 1987–1990.
- [5] Some belt-shaped conjugated systems have been reported since the first synthesis by Herges and co-workers, however, the host properties have not been reported so far: a) S. Kammermeier, R. Herges, *Angew. Chem.* **1996**, 108, 470–472; *Angew. Chem. Int. Ed. Engl.* **1996**, 35, 417–419; b) T. Kawase, H. R. Darabi, M. Oda, *Angew. Chem.* **1996**, 108, 2803–2805; *Angew. Chem. Int. Ed. Engl.* **1996**, 35, 2664–2666; c) S. Kammermeier, P. G. Jones, R. Herges, *Angew. Chem.* **1996**, 108, 2834–2836; *Angew. Chem. Int. Ed. Engl.* **1996**, 35, 2669–2671; d) S. Kammermeier, P. G. Jones, R. Herges, *Angew. Chem.* **1997**, 109, 2317–2319; *Angew. Chem. Int. Ed. Engl.* **1997**, 36, 2200–2202; e) T. Kawase, N. Ueda, K. Tanaka, Y. Seirai, M. Oda, *Tetrahedron Lett.* **2001**, 42, 5509–5511; f) M. Ohkita, K. Ando, T. Tsuji, *Chem. Commun.* **2001**, 2570–2571.
- [6] T. Kawase, Y. Seirai, H. R. Darabi, M. Oda, Y. Sarakai, K. Tashiro, *Angew. Chem.* **2003**, 115, 1659; *Angew. Chem. Int. Ed.* **2003**, 42, 1621.
- [7] a) C. Bingel, *Chem. Ber.* **1993**, 126, 1957–1959; b) A. Hirsch, I. Lamparth, T. Grösser, H. R. Karfunkel, *J. Am. Chem. Soc.* **1994**, 116, 9385–9386; c) E. F. Paulus, C. Bingel, *Acta Crystallogr. Sect. C* **1995**, 51, 143–146.
- [8] Detailed reviews on fullerenes: *Fullerenes: Chemistry, Physics, and Technology* (Eds.: K. M. Kadish, R. S. Ruoff), Wiley, New York, **2000**.
- [9] J. L. Atwood, G. A. Koutsantonis, C. L. Raston, *Nature* **1994**, 368, 229–231.
- [10] T. Suzuki, K. Nakashima, S. Shinkai, *Chem. Lett.* **1994**, 699–702.
- [11] J.-M. Lehn, J. L. Atwood, J. E. D. Davies, D. D. MacNicol, *Supramolecular Chemistry*, Vol. 8, Pergamon, Oxford, **1996**.
- [12] K. Hirose, *J. Inclusion Phenom. Macrocycl. Chem.* **2001**, 39, 193–209.
- [13] Recently, some fullerene complexes with extremely high association constants ( $>10^6$  in benzene) have been reported. These hosts involve transition-metal ions as well as heteroatoms. In contrast, CPPAs are composed of only carbon and hydrogen atoms: a) K. Tashiro, T. Aida, J.-Y. Zheng, K. Kinbara, K. Saigo, S. Sakamoto, K. Yamaguchi, *J. Am. Chem. Soc.* **1999**, 121, 9477–9478; b) O. D. Fox, M. G. B. Drew, E. J. S. Wilkinson, P. D. Beer, *Chem. Commun.* **2000**, 391–392; c) P. D. W. Boyd, M. C. Hodgson, L. Chaker, C. E. F. Rickard, A. G. Oliver, P. J. Brothers, R. Bolskar, F. S. Tham, C. A. Reed, *J. Am. Chem. Soc.* **1999**, 121, 10487–10489; d) D. Sun, F. S. Tham, C. A. Reed, L. Chaker, M. Burgess, P. D. W. Boyd, *J. Am. Chem. Soc.* **2000**, 122, 10704–10705; e) J.-Y. Zheng, K. Tashiro, Y. Hirabayashi, K. Kinbara, K. Saigo, T. Aida, S. Sakamoto, K. Yamaguchi, *Angew. Chem.* **2001**, 113, 1909–1913; *Angew. Chem. Int. Ed.* **2001**, 40, 1857–1861.
- [14] a) Crystal data for **1·3** ( $C_{129}H_{34}O_4$ ): black prism, crystal dimension  $0.4 \times 0.2 \times 0.2$  mm,  $M_r = 1647.69$ ; triclinic, space group  $P1$  (No. 2),  $a = 16.5892(3)$ ,  $b = 18.6608(4)$ ,  $c = 15.5599(2)$  Å,  $\alpha = 105.317(4)$ ,  $\beta = 107.893(2)$ ,  $\gamma = 107.128(2)^\circ$ ,  $V = 4033.7(2)$  Å<sup>3</sup>,  $Z = 2$ ,  $\rho_{\text{calcd}} = 1.356$  g cm<sup>-3</sup>,  $\text{MoK}\alpha$  ( $\lambda = 0.71069$  Å),  $2\theta_{\text{max}} = 55^\circ$ . Intensity data were collected on a Rigaku RAXIS-RAPID Imaging Plate diffractometer at 296 K. The structure was solved with direct methods on  $F^2$  with SHELXS-86. A total of 37335 reflections were collected, 18026 unique reflections were measured and used in the refinement, 1107 parameters,  $R1 = 0.101$ ,  $wR2(Rw) = 0.143$  (0.178) for 5883 reflections with  $I > 2\sigma(I)$ , GOF = 1.67, max. peak in final difference map =  $0.77$  e Å<sup>-3</sup>. All non-hydrogen atoms were refined anisotropically. Hydrogen atoms were placed geometrically and refined by using a rigid model. The high  $R1$  value results from the disorder of included toluene molecules; b) CCDC-199147 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via [www.ccdc.cam.ac.uk/conts/retrieving.html](http://www.ccdc.cam.ac.uk/conts/retrieving.html) (or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB21EZ, UK; fax: (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk).
- [15] a) M. F. Meidine, P. B. Hitchcock, H. W. Kroto, R. Taylor, D. R. M. Walton, *J. Chem. Soc. Chem. Commun.* **1992**, 1534–1537; b) A. L. Balch, J. W. Lee, B. C. Noll, M. M. Olmstead, *J. Chem. Soc. Chem. Commun.* **1993**, 56–58; c) M. M. Olmstead, A. S. Ginwalla, B. C. Noll, D. S. Tinti, A. L. Balch, *J. Am. Chem. Soc.* **1996**, 118, 7737–7751; d) L. J. Barbour, G. W. Orr, J. L. Atwood, *Chem. Commun.* **1998**, 1439–1440; e) M. Fedurco, M. M. Olmstead, W. R. Fawcett, *Inorg. Chem.* **1995**, 34, 388–392; f) D. M. Forkey, S. Attar, B. C. Noll, R. Koerner, M. M. Olmstead, A. L. Balch, *J. Am. Chem. Soc.* **1997**, 119, 5766–5767.
- [16] a) F. Diederich, M. Gomez-Lopez, *Chem. Soc. Rev.* **1999**, 28, 263–277; b) M. J. Hardie, C. L. Raston, *Chem. Commun.* **1999**, 1153–1163, and references therein.
- [17] F. Diederich, *Angew. Chem.* **1988**, 100, 372–396; *Angew. Chem. Int. Ed. Engl.* **1988**, 27, 362–386.
- [18] C. A. Hunter, J. K. M. Sanders, *J. Am. Chem. Soc.* **1990**, 112, 5525–5534; C. A. Hunter, *Angew. Chem.* **1993**, 105, 1653–1655; *Angew. Chem. Int. Ed. Engl.* **1993**, 32, 1584–1586; C. A. Hunter, *Chem. Soc. Rev.* **1994**, 101–109; C. A. Hunter, K. R. Lawson, J. Perkins, C. J. Urch, *J. Chem. Soc. Perkin Trans. 2* **2001**, 651–669.
- [19] a) F. Cozzi, M. Cinquini, R. Annunziata, T. Dwyer, J. S. Siegel, *J. Am. Chem. Soc.* **1992**, 114, 5729–5733; b) F. Cozzi, M. Cinquini, R. Annunziata, J. S. Siegel, *J. Am. Chem. Soc.* **1993**, 115, 5330–

- 5331; c) F. Cozzi, J. S. Siegel, *Pure Appl. Chem.* **1995**, 67, 683–689.
- [20] A. S. Shetty, J. Zhang, J. S. Moore, *J. Am. Chem. Soc.* **1996**, 118, 1019–1027.
- [21] Y.-P. Sun, C. E. Bunker, B. Ma, *J. Am. Chem. Soc.* **1994**, 116, 9692–9699.
- [22] a) R. C. Haddon, *Science* **1993**, 261, 1545–1550; b) M. Kamieth, F.-G. Klärner, F. Diederich, *Angew. Chem.* **1998**, 110, 3497–3500; *Angew. Chem. Int. Ed.* **1998**, 37, 3303–3306; c) L. T. Scott, H. B. Bronstein, D. V. Preda, R. B. M. Ansems, M. S. Bratcher, S. Hagen, *Pure Appl. Chem.* **1999**, 71, 209–219; d) K. K. Baldridge, J. S. Siegel, *J. Am. Chem. Soc.* **1999**, 121, 5332–5333.
- [23] The driving force for fullerene complexation was referred to in the following publications: Z. Yoshida, H. Takekuma, S. Takekuma, Y. Matsubara, *Angew. Chem.* **1994**, 106, 1658–1670; *Angew. Chem. Int. Ed. Engl.* **1994**, 33, 1597–1599; E. C. Constable, *Angew. Chem.* **1994**, 106, 2359–2361; *Angew. Chem. Int. Ed. Engl.* **1994**, 33, 2269–2271; A. Ikeda, Y. Suzuki, M. Yoshimura, S. Shinkai, *Tetrahedron* **1998**, 54, 2497–2508; T. Haino, M. Yanase, Y. Fukazawa, *Angew. Chem.* **1998**, 110, 1044–1046; *Angew. Chem. Int. Ed.* **1998**, 37, 997–998; M. Yamase, M. Matsuoka, Y. Tatsumi, M. Suzuki, H. Iwamoto, T. Haino, Y. Fukazawa, *Tetrahedron Lett.* **2000**, 41, 493–497; S. Mizyed, M. Ashram, D. O. Miller, P. E. Georghiou, *J. Chem. Soc. Perkin Trans. 2* **2001**, 1916–1919; Y. Yamaguchi, S. Kobayashi, N. Amita, T. Wakamiya, Y. Matsubara, K. Sugimoto, Z. Yoshida, *Tetrahedron Lett.* **2002**, 43, 3277–3280.