leads to deactivation of the system.GPC analysis of the polymer indicated $M_n$ and $M_w$ values of 21,000 and 47,900 daltons (Da), respectively, and a DSC curve for the polymer exhibited no detectable exotherm prior to the onset of crystalline melting at 131.6 °C. In contrast, the reactions of (PhSi)(O)VO and (n-Pro)VO under identical conditions gave no polyethylene; the only observable reaction (by $^{13}$C NMR) was metathesis of alkyl ligands on AI for alkoxide ligands on V. 7d98 We have not extensively explored the use of other cocatalysts with 2, but we have observed similar activities with Et$_3$AI and somewhat lower activities with (Me$_3$SiCH$_2$)$_3$AI.

A survey of the catalyst's reactivity indicates that other olefins can also be polymerized or copolymerized, although not as efficiently as ethylene. For example, the reaction of 2 and Me$_3$AI (3 equiv) in propylene (25 °C, ~8 atm, 3 h) gave a small amount (~125 turnovers) of atactic polypropylene 8 (MW < 10,000). Similarly, the copolymerization of ethylene (1%) in neat propylene produced small amounts (~350 turnovers) of copolymer, which contained 5-10% propylene (by $^{13}$C NMR). 9 One olefin that is polymerized well by our catalyst is 1,3-butadiene; an ampule of the resulting product was >95% trans-1,4-polybutadiene. 11

The activity of the catalyst is sensitive to the amount of Me$_3$AI used. As shown in Figure 1, polyethylene production (1 atm, 25 °C, 3 h) is maximized when approximately 3 equiv of Me$_3$AI is used per cocatalyst. Large excesses of Me$_3$AI lead to deactivation of the catalyst. Both observations are contrary to the behavior of typical "soluble catalysts" prepared from trialkylalnanes, which typically require large excesses of alkylaluminum reagents (15-500 equiv) to initiate olefin polymerization. 13 In light of the narrow polydispersity measured for our polyethylene sample (2.28), these results suggest that a well-defined catalyst is being formed 14 and that this catalyst is fundamentally different from these conventional soluble V catalysts.

The presence and equilibration of both 2 and 3 in the starting solution greatly complicate mechanistic studies, but several polymers were polymerized by slowly consuming 3 at -30 °C, where the equilibration of 2 and 3 is negligibly slow, indicate that the active catalyst is derived from the reaction of 2 with Me$_3$AI. Specifically, the addition of Me$_3$AI to an ethylene-saturated solution of 2 and 3 ( ~10:90 by $^{13}$C NMR) at -30 °C initiates ethylene polymerization by slowly consuming 2, but does not affect the amount of 3 in solution. Furthermore, ethylene polymerization is only initiated when the $^{13}$C NMR resonance for 2 is initially present. 15

The active polymerization catalyst(s) in our system is (are) currently not known, and it would be inappropriate to speculate about its identity without additional data. 15 It is, however, important to note that this POMSS-based catalyst is capable of polymerizing olefins when stoichiometrically similar complexes (e.g., (PhSi)(O)VO and (n-Pro)VO) show little or no reactivity. Since our understanding of surface catalysis is both based upon and inherently limited by known reaction chemistry of solution complexes, the unique chemistry of V-containing POMSS may provide new insights into the chemistry of silica-supported vanadium catalysts. Efforts to elucidate the active polymerization catalyst(s) in this interesting system are currently in progress.

Acknowledgement. These studies were supported by the National Science Foundation (CHE-8703016 and CHE-9011593) and an NSF Presidential Young Investigator Award (CHE-8657262). Acknowledgement is also made to the Chevron Research Company and to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research (22376-AC3). F.J.F. gratefully acknowledges financial support from an Alfred P. Sloan Foundation Research Fellowship.

2D Nuclear Magnetic Resonance Study of the Structure of the Fulleren C$_{70}$

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Received January 10, 1991

Geodesic structures were developed by R. Buckminster Fuller on the basis of his insight into their structural economy and stability. In 1985, similar considerations led Smalley, Kroto, et al. to propose that C$_{60}$ observed in carbon cluster beam experiments possessed the geometry of a soccer ball, and they named it "Buckminsterfullerene." Their prediction of the stability of this molecule, as well as other fullerenes, has been stunningly verified by the recent synthesis of macroscopic amounts of C$_{60}$ and C$_{70}$. This development has sparked intense research activity in the production and characterization of these materials. 16 Raman 18

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The resonance position for Cm is in excellent accord with similar carbons in azulene (140.2 ppm), fluorene (141.6 ppm), and 3,5,8-trimethylaceheptylene (143.2 ppm), and 147.8 ppm;28 the downfield position of e is strongly evidence for the icosahedral symmetry of this molecule.5,10

The 1D 13C NMR spectrum for C70, shown in the upper trace of Figure 1, consists of five lines with intensities in the ratio 10:20:10:20:10, as reported by Taylor et al.,8 which strongly supports the D₅₃₅ structure shown in Figure 1. This structure has five chemically distinct kinds of carbon atoms and is similar to the C₆₀ structure with the insertion of 10 forming carbons to form a belt around the molecule. Characterization of the bonding of C₆₀ is important for understanding its structure, and assignment of the NMR lines is critical for their interpretation. An assignment of the resonances of C₆₀ was proposed by Taylor et al.8 based on model compounds and relative strain in the molecule. However, unequivocal experimental assignment of the lines is clearly desirable.

In this communication we show that it is possible to map the bonding connectivities of C₇₀ and obtain definitive resonance assignments by the 2D "INADEQUATE" NMR experiment.22-25 This experiment correlates the 13C NMR line of a carbon to that of its bonded neighbor by excitation of a shared double quantum coherence via scalar J coupling, thus yielding the carbon connectivity map of the molecule. C₇₀ samples enriched to ~20% 13C were used to increase the probability of adjacent 13C atoms, recruiting data acquisition time to 4 days through low solubility. The enriched clusters were prepared by using cored carbon rods loaded with amorphous 13C powder (Cambridge Isotopes) in an arc fullerene generator.6,12,26

The 2D INADEQUATE NMR spectrum of C₇₀ is shown in Figure 1. For this experiment, two bonded carbons share a double quantum frequency in the vertical dimension, and peaks occur at the two respective chemical shifts in the horizontal dimension, allowing the correlation to be made. In addition, each peak will be split into a doublet by the relevant 1JC coupling constant. The D₈₃₅ structure of C₇₀ suggests a linear connectivity of the five carbon types. With the polar carbons (labeled a) representing one end of the connectivity and the belt carbons (e) representing the other. The 2D spectrum reveals the four connectivities, showing a single strong string of connected resonances, with respective intensities 10:20:10:20:10, solidly supporting the D₈₃₅ structure. The crucial connectivity is obtained between the two intensity 10 lines at 150.8 ppm and 147.8 ppm, forcing the assignment of the line at 150.8 ppm to the polar end cap carbon a, and hence the remaining assignments. We note that the resonances correlating to b are the least intense, as only one out of the three bonds of an end cap carbon a connects to a carbon b. In contrast, the belt carbons at 130.8 ppm are each bonded to two type-d carbons at 144.4 ppm, giving cross peaks twice as intense as those revealing the a-b connectivity. The small separation between resonances b and c gives rise to second-order effects in the cross peaks, reducing the outer line of each multiplet.27 These results confirm the assignments of ref 8.

Taylor et al.8 noted that the C₇₀ chemical shifts indicated torsional strain. Belt carbon e resonating at 130.8 ppm can be contrasted to similar carbons in benzo[a]pyrene (125.5 and 123.8 ppm),28 the downfield position of e is consistent with torsional strain (e.g., the bridgehead carbons in paracyclophane18 resonate at 140.4 ppm). However, while carbon a has a similar structural environment to those in C₆₀, it resonates 7 ppm further downfield. The origin of this relative shift is not clear, but may be due to differences in ring currents or aromaticity between the two molecules.29,30

One-bond carbon-carbon coupling constants (IJCC) in polyyclic aromatic compounds generally range from 50 to 64 Hz.31 It has been concluded that the size of the coupling is related to the s character of the bond, and a linear correlation between IJCC and decreasing bond lengths or increasing r-bond orders has been
suggested by several groups for polycyclic aromatic compounds. A value of $J_{6,10}$ of 45 Hz for azulene was interpreted as evidence for this bond being weak. For $C_{60}$, the 2D spectrum gives the $J_{CC}$ values: $J_{ab} = 68$, $J_{bc} = 55$, $J_{cd} = 55$, and $J_{de} = 62$ Hz. These values indicate that the four bonds have substantial $s$ character and $\pi$-bond order. Bonds $d-e$ and $a-b$ fuse six-membered rings and may be compared with $J_{6,10}$ in 1-methyl- and 2-methylnaphthalene at 52 and 53 Hz, respectively. In analogy with cyclopropane derivatives, the larger value of $J_{6,10}$ may arise from both carbons in bond $a-b$ belonging to five-membered rings, whose bonds have greater $p$ character due to smaller internal angles. This should increase the $s$ character of the $a-b$ bond and hence the coupling constant; this effect should be less for bond $d-e$, as this bond has only carbon $d$ in a five-membered ring. We note that the large values for $J_{CC}$ we report support the "rugby ball" bonding topology and coupling constants solidly and in fullerenes.

The 2D NMR spectrum of $C_{70}$ yields bonding topology, coupling constants, and a definitive assignment of the $^{13}$C NMR spectrum. The bonding topology and coupling constants solidly support the "rugby ball" $D_{5h}$ structure for this molecule. The resonance assignments confirm those previously proposed. The $J_{CC}$ values are relevant to investigations of reactivity and bonding in fullerenes.

Acknowledgment. We gratefully acknowledge stimulating discussions with C. S. Yannoni, F. A. L. Aner, G. M. Wallraff, and C. G. Wade, and we thank C. R. Moylan for a critical reading of the manuscript.

Evidence from EXAFS for a Copper Cluster in the Metalloregulatory Protein CUP2 from Yeast

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Expression of yeast metallothionein, which binds copper specifically, is regulated by the protein CUP2 (also known as ACE1). CuP2 itself is activated for binding to DNA by copper(I), which is titrated by thiolate ligands that are likely provided by the 12 cysteines of the protein. How copper is bound to CuP2 is unknown, however. Since stimulation by copper(I) of CuP2 binding to DNA is a cooperative process, and the DNA binding domain of CuP2 contains 12 cysteines, the presence of a copper cluster in CuP2 is also likely. Here we report that Cu K-edge extended X-ray absorption fine structure (EXAFS) gives strong evidence that the coppers bound to CuP2 are sulfur-coordinated and in close proximity to each other, most likely bridged by thiolate sulfur.

Cup K-edge X-ray absorption edge structure demonstrates that the coppers in CuP2 are in the $+1$ oxidation state and furthermore indicates that their electronic environment is closest to 3-fold coordination. Cu K-edge X-ray absorption spectra were collected at the Stanford Synchrotron Radiation Laboratory on wiggler beam line 4-2 (unfocused) under dedicated ring conditions (3 GeV, 70-90 mA) using a Si(220) double-crystal monochromator. Protein

Figure 1. EXAFS data for CuP2. The solid line is the raw data. The dashed line is the data obtained by Fourier transforming the data into $R$ space, applying a filter from 0.80 to 3.35 Å, and back-transforming. The dotted line is the calculated EXAFS from two-shell fits described in the text and reported in Table I.

Figure 2. Comparison of the Fourier transform on filtered EXAFS data ($R = 0.80-3.35$ Å, $k$ range of $3.0-10.0$ Å$^{-1}$) from CuP2 (solid line) with transforms of a one-shell fit containing S (dashed line) and a two-shell fit containing S and Cu (dotted line). Notice the excellent agreement between the fit and data for the first shell in both cases. However, while the second peak is not reproduced by a single S shell, it is well reproduced with the presence of a second shell of Cu.


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